THE UNIVERSITY OF ALBERTA

THE CARBONATE COMPLEX AND LEAD-ZINC ORE BODIES, PINE POINT, NORTHWEST TERRITORIES, CANADA.

by

© STEWART ALBERT JACKSON

A THESIS

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies for acceptance, a thesis entitled, "The Carbonate Complex and Lead-zinc Ore Bodies, Pine Point, Northwest Territories, Canada", submitted by Stewart Albert Jackson, in partial fulfillment of the degree of Doctor of Philosophy.

ABSTRACT

The Middle Devonian carbonate complex, Pine Point, District of Mackenzie, Canada, is composed of five carbonate units. The Pine Point, Presqu'ile and Sulphur Point Formations form a linear barrier carbonate complex over 600 feet thick and 12-15 miles wide that intertongues with shales of the Buffalo River Formation to the north and evaporites of the Nyarling Formation to the south. These formations are overlain by the Fort Vermilion Formation and the Slave Point Formation, an extensive 75-foot thick evaporitic carbonate and a 170-foot thick limestone unit respectively. Rich Mississippi Valley-type lead-zinc sulphide ore bodies occur within the dolomites of the Pine Point and Presqu'ile Formations.

During the initial phase of deposition of the Pine Point Formation, the barrier carbonate complex accumulated as a series of open marine banks along a major fault trend. This complex then developed into a basin-restricting barrier with well-defined fore-reef, reef, and back reef lithofacies and faunas. Evenly bedded strata of the Presqu'ile Formation and the Sulphur Point Formation that lie between the Pine Point and Fort Vermilion Formations accumulated in a generally more restricted environment. Scattered patch reefs and banks of corals and stromatoporoids protected the northwesterly seaward side of the complex. The barrier itself consisted mainly of Amphipora-rich sediments that had accumulated in shallow lagoons. Lesser tidal and supratidal flat deposits, and sabkha-type deposition complicate the picture. The end of the barrier phase is marked by a number of fresh-water shales deposited over the carbonate complex.

Shallow marine to subaerial conditions prevailed during deposition of the Fort Vermilion Formation. This resulted in a mosaic of shallow

subtidal, intertidal, supratidal and sabkha sediments. Subsequently, the more open-marine limestones of the Slave Point Formation blanketed the area.

Complex diagenetic changes undergone by the carbonate complex include: synsedimentary and late-stage dolomitization, karst development, and porosity occlusion by lead-zinc sulphides, bitumen, native sulphur and calcite. The late-stage dolomitization was associated in part with thermal brines moving through the complex. Solution and re-precipitation of earlier-formed dolomite, and some dolomitization of limestone, created the coarsely crystalline dolomite of the Presqu'ile Formation.

The ore bodies are epigenetic in nature and occur as scattered elongate lenses with sharp margins. They are in part localized by breccia zones. Sulphur isotope ratios indicate that the sulphur in the ores was probably derived from sulphates associated with the carbonate complex. Lead isotope determinations do not conclusively indicate the origin of the metals. However, analysis of shales, carbonates, and oilfield brines indicate that sufficient metals to form the ore bodies could have been carried up-dip from the basin to the west by compaction-generated brines.

ACKNOWLEDGMENTS

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Thanks go also to Dr. F.W. Beales, University of Toronto, under whose direction much of the field work and laboratory preparation for this project was done, for his continued interest and help in this study. Discussions with Dr. P. Fritz based on his oxygen and carbon isotope studies contributed to a better understanding of the dolomitization. Dr. A. Sasaki's work on sulphur isotopes elucidated the genesis of both the orebodies and the native sulphur commonly found throughout the carbonates. Cominco Ltd. and Pine Point Mines Ltd. provided financial support for field work and permitted free access to their records, drill cores, and mining operations. The staff of both companies assisted greatly in many ways toward the completion of this project. Special thanks go to R.G. McEachern, Cominco Ltd., for his help and interest throughout the project, and to W.T. Irvine, S.M. Richards, W.E. Wiley, and F.S. Hurley of Cominco Ltd. for numerous discussions and criticisms. Conwest Exploration Ltd. generously provided access to their cores. The University of Alberta provided research facilities and financial support for the project (NRCA-2810). The Province of Alberta provided financial support in the form of a Province of Alberta loan and grant.

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CHAPTER 1: INTRODUCTION

INTRODUCTION

This study developed from the knowledge that, prior to development of the great orebodies at Pine Point, a critical geological area and stratigraphic interval had been systematically drilled by Cominco Ltd., and approximately half a million feet of diamond drill core had been accumulated. These cores offered an opportunity to study

1. The genesis of a Middle Devonian carbonate that had been variously termed a barrier reef, facies front, carbonate edge, barrier edge, and reef complex, and
2. The post depositional diagenetic changes of this complex with its important economic significance.

The ultimate potential of this great mass of subsurface stratigraphical data was obviously beyond the scope of a single thesis project, but it is hoped that a contribution has been made which is helpful and which may serve as a basis for further and more detailed studies.

It was not anticipated that the Pine Point data would provide material to rival the paleoecological studies that have been generated by description and analysis of limestone reef complexes. Rather, the thesis is in part an exercise in applied paleoecology because the superb control provided by the numerous holes drilled has made it possible to recognize parallels and differences in a carbonate complex in which details have been almost completely obliterated by dolomitization. This constitutes an important research effort since dolomitized carbonate complexes are much more common and economically much more important than undolomitized limestone accumulations.

The economic importance of the Middle Devonian, Presqu'ile and Pine

Point dolomites lies in the reserves of lead and zinc sulphide ores of Mississippi Valley-type that occur in the vicinity of Pine Point, District of Mackenzie, Canada. Also, these dolomite units form part of a major barrier carbonate complex which controlled extensive evaporite deposition over much of Western Canada during Middle Devonian time.

In addition, major gas reserves have been developed in dolomites in the subsurface extension of this carbonate complex in northeastern British Columbia. Major oil and gas reserves have also been found in the generally dolomitized, laterally equivalent pinnacle reefs of the Rainbow and Zama Lake areas of northwestern Alberta. An understanding of the mode of development of the carbonates in the Pine Point area could lead to a better understanding of the nature of these important hydrocarbon reservoirs.

The thesis reports the results of detailed examination of the stratigraphy of the carbonate complex in the Pine Point area, the paleoecology of its development, and post depositional changes that it has undergone. An advantage of the Pine Point studies lay in the availability of more numerous "off-reef" cores than had been available from most oil exploration drilling data. These permitted actual rather than inferred cross section reconstructions of the carbonate facies front.

Preliminary studies on the mineralization had revealed that problems of stratigraphical nomenclature regarding parts of the sequence were inhibiting regional analysis. With the developing emphasis on stratigraphic data-processing by computers, it is essential that input data be assembled in comparable formats. This study more adequately clarifies the correlations of some 100 feet of beds which had been

formerly little understood.

It is hoped that the studies reported here will help to maintain the tempo of economic activity that has developed in recent years in the Great Slave/Zama-Rainbow area.

HISTORICAL INTRODUCTION

The lead-zinc deposits of the Pine Point area, on the south shore of Great Slave Lake, District of Mackenzie, Canada (see location map, Fig.1), were known to the local Indians before the turn of the century. However, attention was not focussed onto this area until 1898 when the ore deposits were pointed out to prospectors travelling northward, via the inland water route, to the gold fields of Alaska and the Yukon Territory. Shortly afterwards the deposits were staked and intermittently prospected and explored until 1947, when a major renewed effort at exploration was begun under the direction of Cominco Ltd. By 1955 this phase of work had outlined a large mineralized area. Hurdle (1964) summarized the early exploration activity in the area, and a summary of both early and recent economic developments in the area is given in Appendix A.

A decision was reached in 1961 to build a railway to the area, and the property came into production in 1965 at the rate of 5,000 tons per day with reserves of 21.5 million tons averaging 4 percent lead and 7.2 percent zinc. Published reserves at the end of 1969 were 41.8 million tons averaging 2.4 percent lead and 6.3 percent zinc, and a good potential exists for further expansion of reserves.

The nature of the ores and the surrounding rocks was first described by Robert Bell of the Geological Survey of Canada in 1899 who noted "the occurrence of galena and blende in the Devonian limestones"

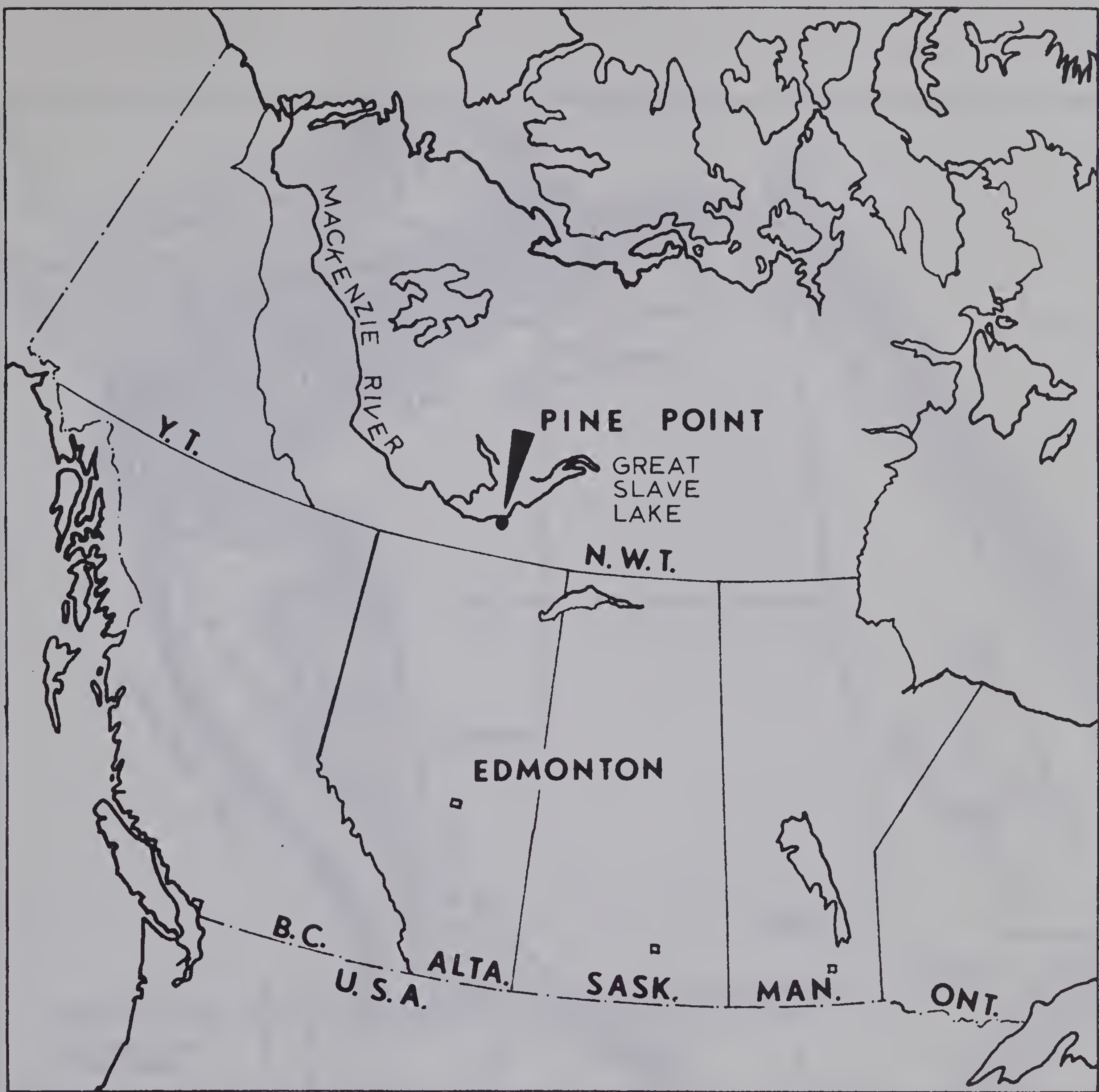


FIG. 1: LOCATION MAP, PINE POINT.

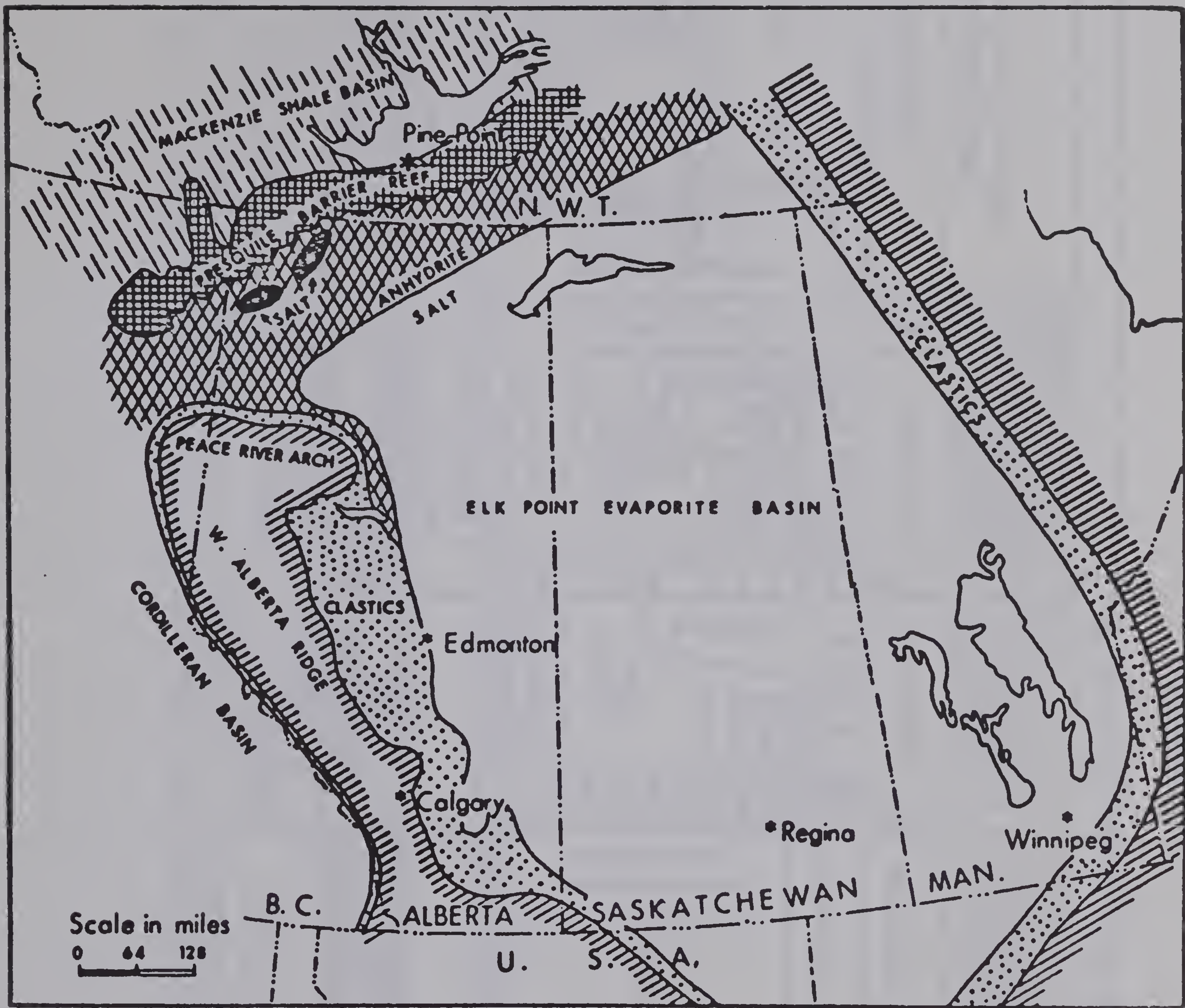
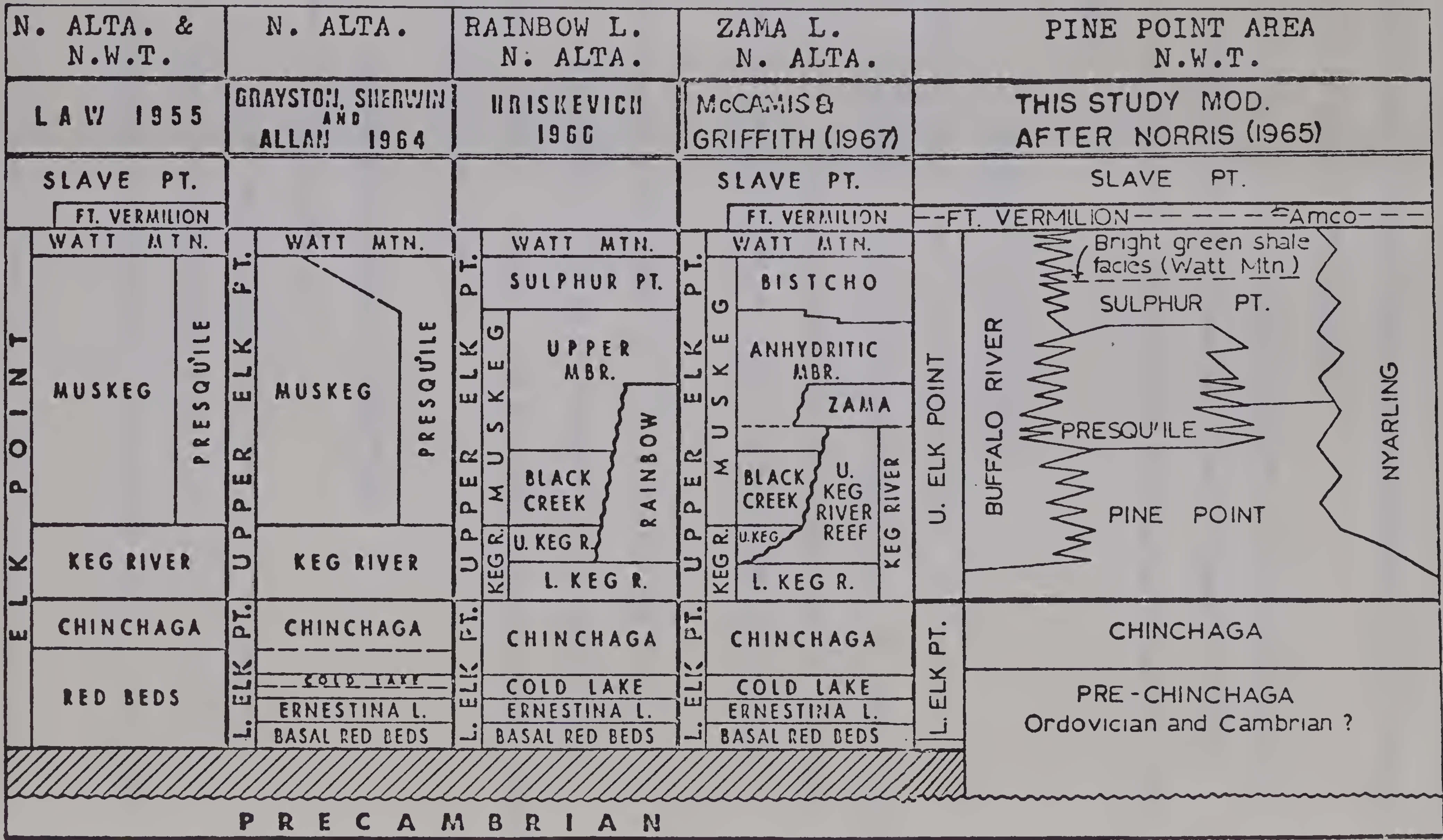


Fig. 1A. Location map illustrating the position of Pine Point and the paleogeography of Western Canada during deposition of the Middle Devonian Presqu'ile barrier reef complex. (mod. from Grayston, Sherwin and Allan, 1965).

TABLE 1: NOMENCLATURE AND RELATIONSHIP OF HOMOTAXIAL ROCK UNITS NORTHERN ALBERTA AND NORTHWEST TERRITORIES (after McCAMIS AND GRIFFITH, 1967).



(Bell, 1902, p.108). MacIntosh Bell later classified the ores as being of Mississippi Valley type (Bell, 1929), and noted that the ore deposits occurred in dolomite which had been described by Cameron (1918) as the Presqu'ile dolomite of Middle Devonian age.

A number of publications have since appeared on the regional and local geology. A bibliography of these is given by Campbell (1966). Among the most recent workers on the regional setting are Norris (1965) and Richmond (1965).

LOCATION OF STUDY AREA

The study area surrounds the town of Pine Point, (situated at latitude 60°50'N., longitude 114°27'W.) on the south side of Great Slave Lake as shown on Fig.2. It is approximately 200 square miles in extent and is enclosed by the dotted line on Fig.2, and the south shore of Great Slave Lake.

Access to the area may be gained by air as far as Hay River, located 50 miles to the west, or by an all-weather road running 375 miles from Grimshaw, Alberta. A spur from the Great Slave Lake Railroad at Hay River provides freight service.

PURPOSE AND SCOPE OF THE STUDY

The objectives of this study are:

1. To elucidate the nature and geological history of the lead-zinc bearing carbonate complex underlying the Pine Point area, through a study of the stratigraphy, the application of paleoecology and analysis of facies.

2. To examine the nature and distribution of the coarsely crystalline dolomite of the Presqu'ile Formation and to determine the history of

dolomitization.

3. To clarify the correlations of strata between the Amco marker and the Watt Mountain shale that had been differently assigned or unclassified by earlier definitions of formational boundaries.

Examination of stratigraphy is confined mainly to the study area, and as a recent Geological Survey of Canada Memoir (Norris, 1965) encompasses the area, the reader is referred to it for lists of fossils and age of strata in the area, and for correlations beyond the study area. Because much of the carbonate complex has been dolomitized, paleoecology is applied rather than studied *per se*, as an aid to facies analysis and interpretation.

Attention is further focussed on a particular stratigraphic interval that includes the Pine Point, Presqu'ile, Sulphur Point, and the basal part of the Slave Point Formation. The underlying Chinchaga and earlier sediments, and the overlying upper part of the Slave Point Formation are not treated in detail.

Diagenetic alteration of the sediments is extremely complex and the present study represents only a reconnaissance of the total problem. Development of the various dolomites and mineralization by lead and zinc sulphides are the main aspects investigated.

METHOD OF STUDY

General

The area is one of low relief with predominantly black spruce cover on muskeg terrain relieved by numerous pine covered Pleistocene beach ridges. Outcrop is scarce with only a few exposures in the vicinity of ridges and river cuts. Information on the geology of the area is, of necessity, derived mainly from diamond drill core and exposures created

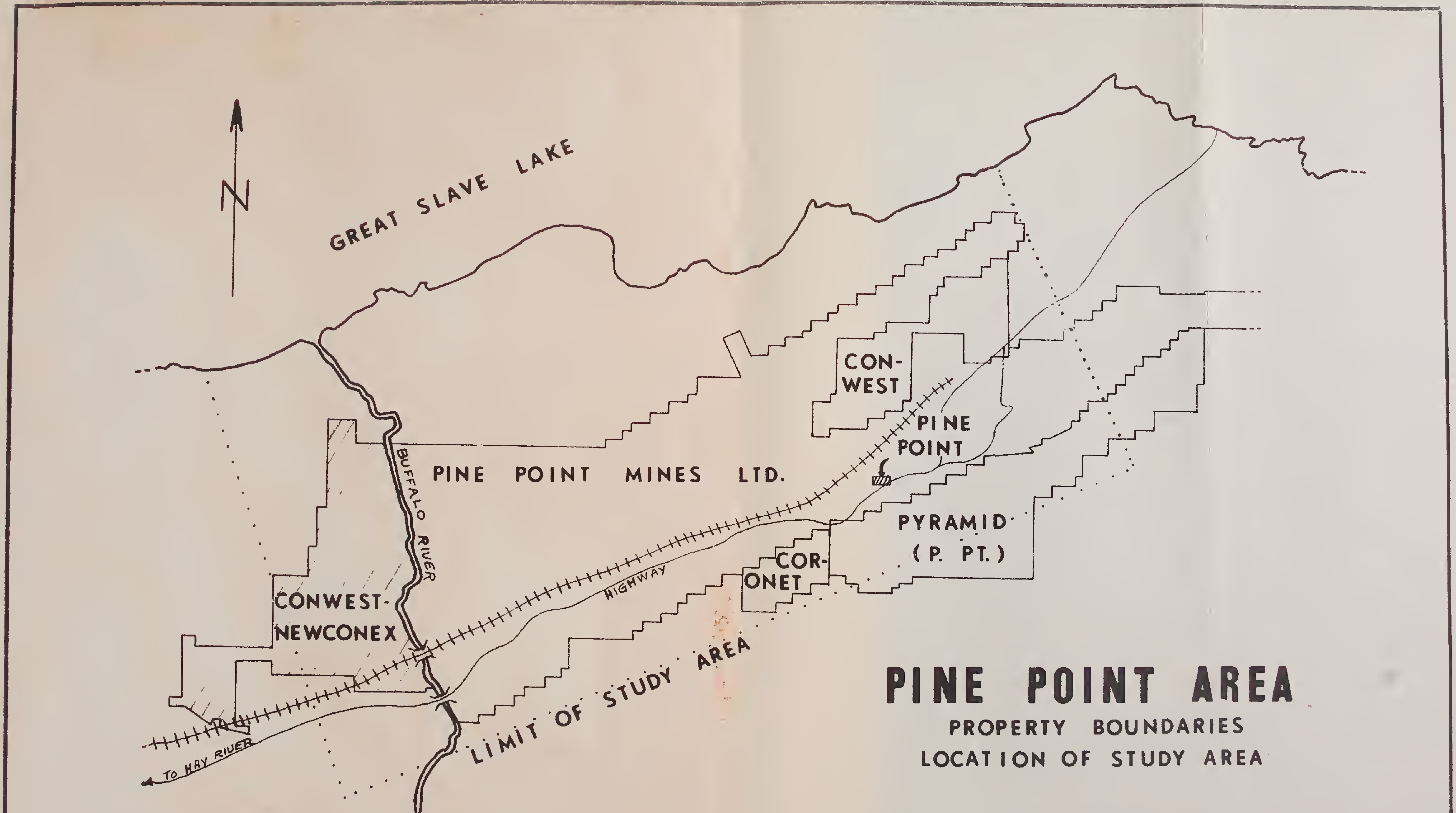

N
GREAT SLAVE LAKE
PINE POINT MINES LTD.
BUFFALO RIVER
CONWEST-NEWCONEX
CON-WEST
PINE POINT
PYRAMID (P. PT.)
COR-ONET
HIGHWAY
LIMIT OF STUDY AREA
To HAY RIVER
1 2 4 6
scale in miles
PINE POINT AREA
PROPERTY BOUNDARIES
LOCATION OF STUDY AREA

FIG. 2

by mining operations.

By the summer of 1965, several hundred thousand feet of drill core from over 1,300 exploration diamond drill holes and several hundred detailed drilling holes were available for study. Some of these cores were from drilling done as long ago as 1947, but most of the core fortunately had been stored and was still in good condition. By 1965 mining operations had exposed sections of strata in three separate open pits. Several pits have been opened since that time. The writer spent three months in the summer of 1965, two weeks in 1967, and three days in July, 1969, logging cores and examining pit walls. Outcrops in the study area were examined briefly.

In order to retain a legacy of drill hole numbering and cross section labelling, the Pine Point Mines system has been followed for the thesis. A key map (Fig.A1) provides locations of drill holes and sections. Diamond drill holes were numbered consecutively as drilled, resulting in the present somewhat random distribution of numbers. The twelve cross sections (Figs.A2-A13) and one longitudinal section (Fig.A14) are included in the map pocket.

Ninety-two cores were logged from storage and from new drilling at Pine Point. Samples were taken at 5-10 foot intervals within each stratigraphic level in each core logged. Samples from forty of these cores were slabbed and half of each sample was polished. The other half was stained with Alizarin red S for gypsum/anhydrite and calcite following methods of Friedman (1959). About 100 thin sections were made from selected intervals. In addition a number of sections were examined from specimens selected for oxygen and carbon isotope work. A few acetate peel prints were made following the methods of Beales (1960) but were

found to be inferior to thin sections and polished slabs, especially for dolomites.

In the preliminary stages of the project at the University of Toronto, clustering techniques, using up to 45 variables per specimen following the method of Bonham-Carter (1965), were attempted in an effort to break the Presqu'ile Formation into facies. Only random patterns were obtained from initial runs and this line of attack was not continued at the University of Alberta.

Petrographic microscope and binocular microscope examinations were made of the thin sections, peel prints, and the variously prepared slabbed cores.

Method of Drawing Cross Sections

The rocks of the Pine Point area have been subjected to tectonic forces resulting in broad folds of small amplitude. The effects of folding have been removed for purposes of illustration and interpretation by using the Amco marker as a datum where possible, and the underlying C markers and D3 marker bed where the Amco marker is eroded.

The Amco marker is a useful datum since it is persistent in lithology and thickness throughout most of the Pine Point area and may be considered a para-time rock-unit. When the Amco marker is used as a datum, the other marker beds (C and D3) lie parallel to it in cross sections, and other stratigraphic features such as intraclast beds in the Slave Point Formation, and gypsum lenses within the Sulphur Point Formation also lie approximately parallel to the Amco bed.

The effect of minor block faulting after Amco deposition is also removed by this method of reconstruction. The extent of tectonic influence can be seen in the longitudinal section in this study (Fig.A14)

and in illustrations in Norris (1965, Fig.7).

TERMINOLOGY USED

The classification of carbonates has been discussed at length in a recent A.A.P.G. Memoir edited by Ham (1962) and in a summary paper by Bissell and Chilingar (1967). However, most classification systems deal largely with limestones and the 'crystalline rocks,' especially dolomites, are characteristically given little attention beyond grain size designation.

Suites of Middle Devonian dolomites similar to those encountered in this study have been studied by Griffin (1962), Pfaff (1967), Langton and Chin (1968), and McCamis and Griffith (1968). Griffin (1962, p.24) grouped the dolomites of the Slave Point Formation of northeastern British Columbia into six textural categories: Micro-inclusion, macro-inclusion, banded, clotted, nebulous, and pseudo-brecciated. Pfaff (1967) separated the Rainbow B pool dolomites into textural groupings similar to those of Griffin. Langton and Chin (1968) distinguished dolomite facies in the Rainbow Lake reefs which required no special new terminology.

Both the complex dolomites and limestones of this study are described and grouped using the terminology of Folk (1962). The terms reef, bank, bioherm and biostrome are used in the sense of Nelson, Brown, and Brineman (1962, p.250). In addition, the term carbonate complex is used when referring to some or all of the linear carbonate accumulation lying between a sequence of shales to the north and a sequence of evaporites to the south. The term is general and is used where no specific ecological connotation is inferred to avoid incorporation of the terms barrier, reef, and bank.

CHAPTER 2: STRATIGRAPHY

GENERAL SETTING

The study area (Fig.2) lies on the eastern margin of the western Canada sedimentary basin about 50 miles west of the exposed Precambrian Shield. Paleozoic sediments some 1,300 feet thick in the Pine Point area form a general homoclinal succession striking north-northwest and dipping about 20 feet per mile toward the west-southwest. Two major southwesterly trending basement faults in the Precambrian Shield (Fig.3) can be traced under the area (Burwash, 1957; Norris 1965, p.87) and may have been active in the early Paleozoic. Block fault movements or minor faulting may have occurred in the area during the late Middle Devonian as Norris (1965, p.89) suggests that faulting occurred at this time on the northwest side of Great Slave Lake. Faulting may also have occurred during the Permian and later (Sikabonyi and Rodgers, 1959, p.214).

EARLY STRATIGRAPHIC WORK

The first geological map covering the area was probably that of Isbister (1855) which showed Precambrian (Crystalline), Silurian, and Devonian rocks on the south shore of Great Slave Lake. A number of reports followed including those of McConnell (1891), Camsell (1915), and Cameron (1918). Cameron conducted a detailed survey of the area and recognized three formations within a sequence that he dated as Middle Devonian: 1. the Pine Point limestones, 2. the Presqu'ile dolomites, and 3. the Slave Point limestones.

Following prospecting of the lead-zinc deposits in the Presqu'ile Formation to the south of Pine Point, a number of reports appeared including those by R. Bell (1902), and J. M. Bell (1929, 1930, 1931).

Detailed drilling after 1946 brought about recognition of complex facies changes in the area that were described by Campbell (1950, 1957, 1966, and 1967). Law (1955a,b) introduced new terminology for the Elk Point Group in northwestern Alberta and correlated formations of the Pine Point area with their subsurface counterparts.

Warren and Stelck (1956) illustrated typical assemblages of fossils from the Pine Point and Presqu'ile Formations.

The Pine Point area was later mapped during Operation Mackenzie, a major helicopter reconnaissance mapping project of the Geological Survey of Canada. From this and other work, preliminary maps and reports (Douglas, 1959; Douglas and Norris, 1960) and a memoir (Norris, 1965) were published. The general geology of the area is shown in Fig.3 (after Norris, 1965). W. O. Richmond, under the auspices of Pan American Petroleum, mapped the area (circa, 1960) and studied the stratigraphy and sedimentation of the Slave Point Formation as a Ph.D. project at Stanford University (unpublished thesis, 1965). The stratigraphy has since been reviewed by Campbell (1967).

For bibliographies and more details of previous work the reader is referred to Norris (1965) and Richmond (1965).

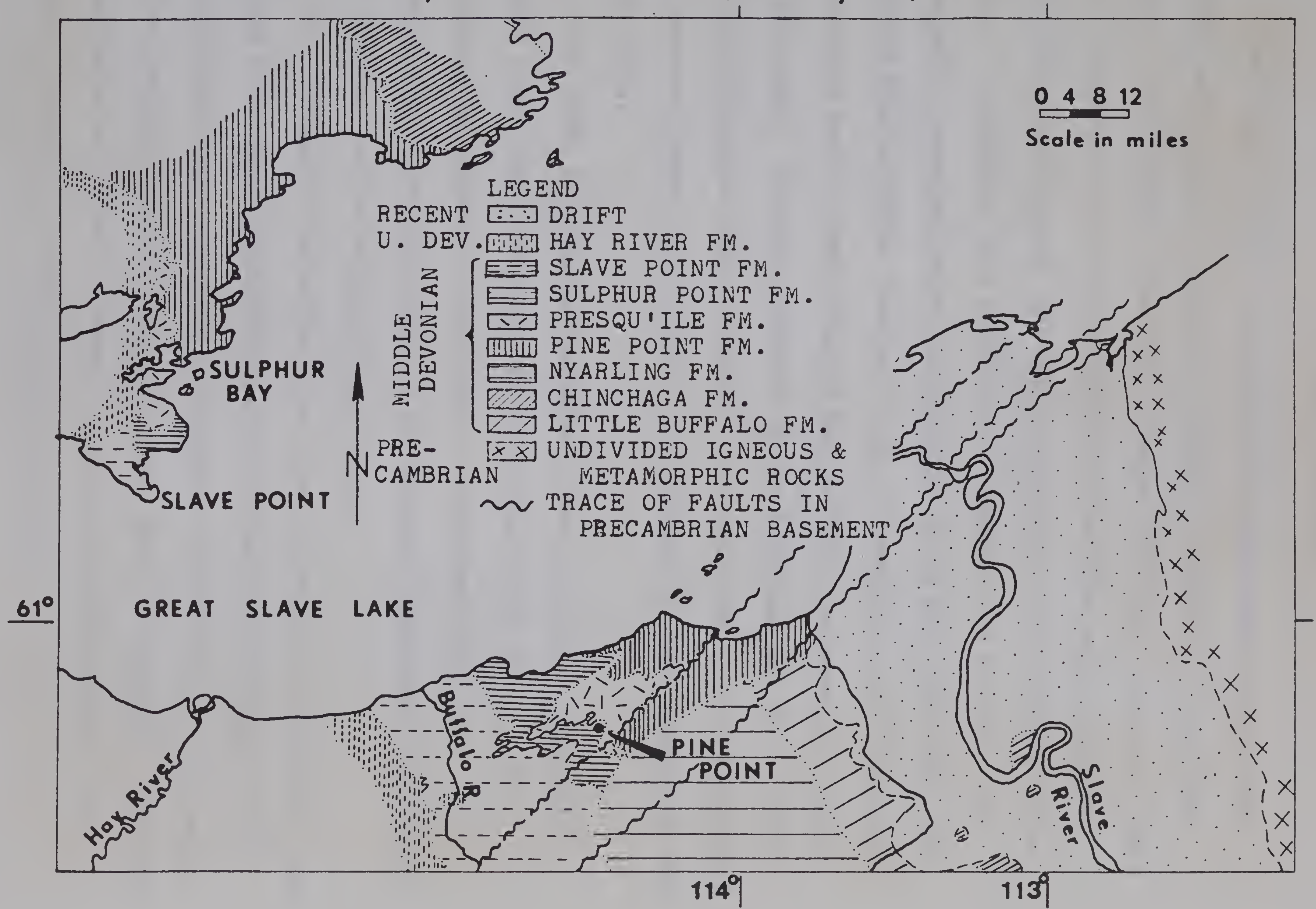
REGIONAL CORRELATION

The Pine Point area is underlain by a succession of Paleozoic strata, approximately 1,300 feet thick, on granitic Precambrian basement. The basal 230 feet of the Paleozoic is Ordovician and Cambrian? in age (Rice, 1965, p.9). The remainder is Middle Devonian (Norris, 1965, p.12) except for a thin capping (10 feet--erosional edge) of Upper Devonian strata.

The Middle Devonian strata examined in this study were assigned

mainly to the Elk Point Group by Law (1955a,b). Later workers subdivided the Elk Point into a Lower and Upper Subgroup (see Table 1). This study is concerned mainly with the Upper Elk Point Subgroup and the overlying Slave Point Formation. Correlation of nomenclature with subsurface equivalents in northern Alberta and the southern District of Mackenzie is shown in Table 1. For detailed correlations throughout the southern District of Mackenzie the reader is referred to Norris (1965, Fig.3).

FIG.3: GENERAL GEOLOGY, PINE POINT AREA (NORRIS, 1965).



DETAILED MIDDLE DEVONIAN STRATIGRAPHY OF THE STUDY AREA

The Middle Devonian succession within the study area has been established by Norris (1965, p.31, Fig.3) to consist of four major units: the Chinchaga, Pine Point, Presqu'ile/Sulphur Point, and Slave Point Formations. In this work parts of the above units are given formational rank; namely, The Buffalo River and Fort Vermilion Formations. In addition, Rice (1967, p.9) recognized the Cold Lake and Fitzgerald Formations below the Chinchaga in the Pine Point area, and regarded them as Middle Devonian in age. However, Rice's results are unpublished and the terminology of Norris (1965) is generally followed in this study. With the exception of the Chinchaga, all of the Middle Devonian formations listed outcrop in the study area and are intersected by numerous diamond drill holes. The Chinchaga has been sampled by only a few cores.

This study is concerned mainly with the Pine Point, Presqu'ile, Sulphur Point, Fort Vermilion, and basal Slave Point strata. The succession is presented in the table of formations (Table 2). The relationships of the rock units in the area are illustrated in a general way in Fig.4, and in detail in Figs.A2-A14.

The carbonate rocks of the Pine Point and Presqu'ile Formations form a prism 15-20 miles wide trending east-northeast perpendicular to the strike of the basin shales, and argillaceous limestones lie to the north of the carbonate belt and evaporitic rocks occur to the south. The prism of carbonate is commonly referred to as the Presqu'ile barrier reef (Grayston, Sherwin, and Allan, 1964, Fig.5-11D).

Table 2: Table of Middle Devonian and younger formations for the study area (modified from Norris, 1965).

ERA	Period or Epoch	Formation or Member	Thickness (feet)	Lithology and Distribution
	Pleistocene (Wisconsin) Recent		----	Till, beach gravel, sand dunes, glacial lake clays
	Unconformity			
PALEOZOIC	Upper Devonian (Frasnian)	Hay River	11 max.	Fossiliferous argillaceous limestone and blue-green shale; erosional remnant in extreme west of study area
	Unconformity			
	Middle Devonian (Givetian)	Slave Point	170+	Bedded brown fine-grained limestones with beds of subspherical stromatoporoids; some laminated carbonaceous limestones
		Fort Vermilion	73±	Interlaminated anhydrite and aphanocrystalline dolomite; laminated brown limestone and mottled fine-grained mottled dolomite. Amco marker, 10 feet thick, of argillaceous dolomitic limestone lies near middle of section
		Sulphur Point	0-145	Mainly white biosparite and pelsparite; lenses of bright green waxy shale (Watt Mountain) near top; massive brown limestone and finely crystalline brown dolomite lie on, and are laterally equivalent to the white limestone

Table 2 (continued)

ERA	Period or Epoch	Formation or Member	Thickness (feet)	Lithology and Distribution
PALEOZOIC	DEVONIAN (Givetian)	Presqu'ile	0-200	Very coarsely crystalline to extremely coarsely crystalline vuggy dolomite (a diagenetic unit in part, see text)
		Nyarling	420?	Gypsum, minor limestone, probably some dolomite; poorly exposed to the south of the study area
		PINE POINT FORMATION: Fine-grained Dolomite Member	0-460	Aphanocrystalline, cohesive brown dolomite to medium crystalline friable brown dolomite
	— ? — ? —	PINE POINT FORMATION: Bituminous shale, limestone and dolomite Member	0-140+	Bituminous brown limestone with bituminous shaly partings, usually petroliferous; dark brown medium to coarsely crystalline dolomite; some beds richly fossiliferous. Occurs at surface at Dawson Landing (east of study area)
	MIDDLE (Eifelian)	PINE POINT FORMATION: Limestone Member	0-110	Medium brown limestone and brownish grey shale, penetrated by only the Cominco G-4 well in thesis area
		Chinchaga	295-337	White to light brown anhydrite interlaminated with aphanocrystalline brown dolomite; limestone and dolomite breccia and minor green shale; does not outcrop in study area

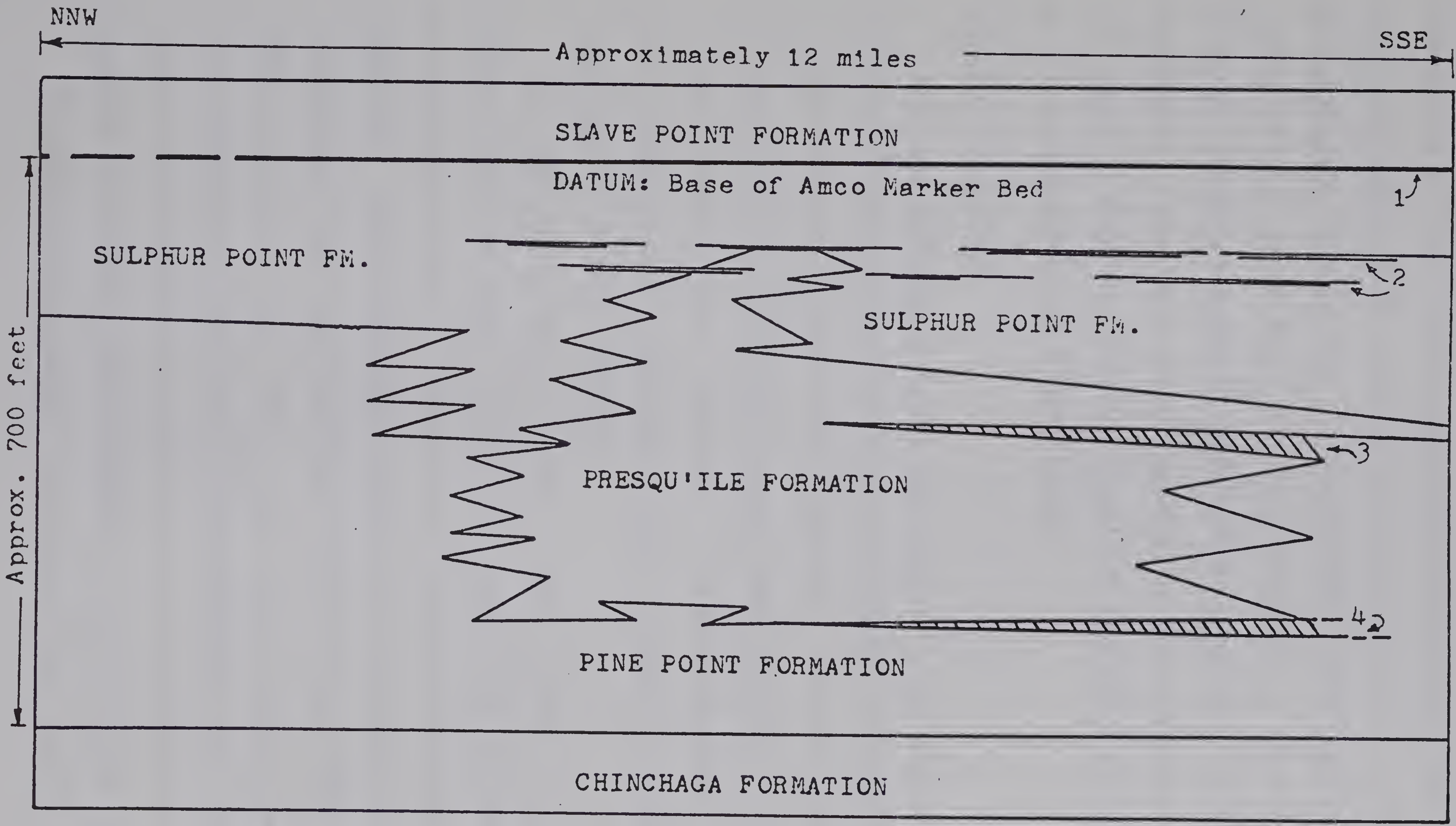


Figure 4: Relationship of Middle Devonian Formations and marker beds in the study area (diagrammatic, not to scale). Markers: 1= Amco bed, 2 = Watt Mountain shale beds, 3 = C marker beds, 4 = D3 bed.

The Pine Point, Presqu'ile, and Sulphur Point Formations have been established to be of Middle Devonian age by Warren and Stelck (1962, p.275) and Norris (1965, pp.10-14) on the basis of the occurrence of Stringocephalus burtini s.l. Audretsch (1967, p.846) confirmed the Middle Devonian age of these units on the basis of a spore assemblage from the laterally equivalent Buffalo River Formation. No additional contribution was made to the paleontology in this study and accordingly the reader is referred to Norris (1965) for discussion of faunal lists and biostratigraphic age determinations.

CHINCHAGA FORMATION

The name Chinchaga Formation was proposed by Law (1955a,b) for the basal unit of the Elk Point Group in the subsurface of northwestern Alberta. The type section of the formation is the interval from 5,475 to 5,680 feet in the California Standard Steen River No. 2-22 well (Lsd. 2, Sec.22, Tp.117, Rge.5, W.6th mer.). The lithology varies from light grey to brown anhydrite with minor amounts of brown to brownish-grey, very finely crystalline dolomite.

The Chinchaga underlies the entire study area but is completely cored in only three holes: Cominco G-1, Cominco G-4, and Pyramid 202A. The formation averages 316 feet in these holes and consists of 'white to light brown, crypto-crystalline anhydrite with interbeds of micro- to medium-grained light brown anhydritic dolomite' (Rice, 1967, p.52). Rice (1967, p.53) stated that: (1) the lower contact with the lower Elk Point evaporites is sharp and may be disconformable, and (2) the upper contact of the formation is gradational and is placed at the highest occurrence of anhydrite below carbonates of the Pine Point Formation.

The Chinchaga was examined only briefly during the field study and

readers are referred to Belyea and Norris (1962), Norris (1965), and Rice (1967) for further details on lithology and correlation.

PINE POINT FORMATION

The name Pine Point limestones was proposed by Cameron (1918, pp.25, 26) for Middle Devonian strata exposed at Resolution and at Pine Point on the south shore of Great Slave Lake and on ridges south of Pine Point. These are the type areas but no specific type section was established.

The term Pine Point was subsequently used for various exposures of strata in the Great Slave Lake area as summarized by Norris (1965, p.45). Norris (1965, p.45) redefined the Pine Point Formation to include all strata between the top of the Chinchaga Formation and the base of the coarsely crystalline dolomite of the Presqu'ile Formation or the base of the limestones of the Sulphur Point Formation. His definition is retained in this study except that the shaly Buffalo River Member is removed from the Pine Point Formation and is reinstated as a Formation.

The Pine Point Formation has a total thickness of 550 and 537 feet in the Cominco G-1 and Cominco G-4 wells respectively (Douglas, 1959, pp.40,42), and conformably overlies the Chinchaga Formation, with the contact placed at the uppermost anhydrite occurrence (Rice, 1967, p.54). The upper contact with the Presqu'ile and Sulphur Point Formations is differently defined for each member of the Pine Point Formation.

Norris (1965, p.46) subdivided the Pine Point Formation of the study area into four members:

1. Bituminous shale and limestone member
2. Limestone member
3. Fine-grained dolomite member
4. Buffalo River Member

The bituminous shale and limestone member has been redefined here to include some dolomite and is termed the bituminous shale, limestone, and dolomite member. The limestone member is intersected by only the Cominco G-1 well and is not examined in detail in this study. The limestone member is close to 83 feet thick and lies between the Chinchaga Formation (below) and the fine-grained dolomite member of the Pine Point Formation (above) in the interval 592.3 to 675.0 feet in the Cominco G-1 well (Norris, 1965, pp.46-47).

The relationships of the members (except the brown limestone member) are illustrated in a general way in Fig.5 and in detail in Figs.A2-A14.

Bituminous Shale, Limestone, and Dolomite Member

Underlying the northern margin of the study area is a facies characterized by dark brown argillaceous limestone and minor bituminous shale with abundant brachiopods and echinoderm fragments. Norris (1965) designated this as the bituminous shale and limestone member of the Pine Point Formation from outcrops of the type area for the Pine Point Formation (Cameron, 1918, pp.71-72) in the vicinity of Dawson Landing (Fig.A1). The outcrops were examined briefly in the course of this study and data was derived largely from core examination.

Norris (1965, p.49) described two main rock types; one consisting of 'dark, strongly calcareous bituminous shale thinly interbedded with medium to dark brown fine-grained to aphanitic, in part nodular limestone' partly rich in fossils. The other overlying lithology consists of brachiopod-rich 'medium to dark brown, irregularly thin-bedded, very fine-grained to aphanitic, in part petroliferous limestone, weathering a medium brownish grey.'

In subsurface both these distinctive lithologies are dolomitized in

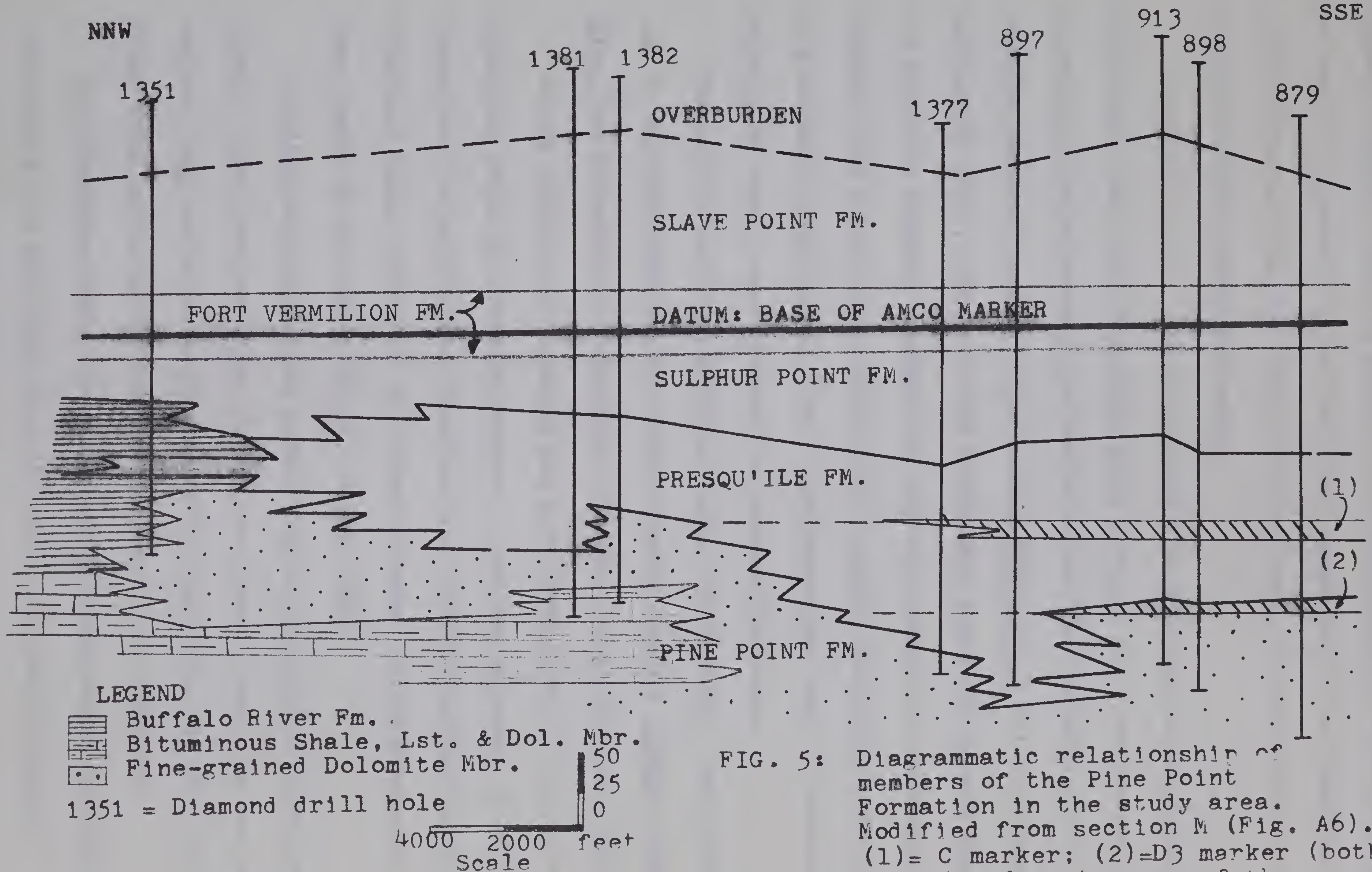


FIG. 5: Diagrammatic relationship of members of the Pine Point Formation in the study area. Modified from section M (Fig. A6). (1)= C marker; (2)=D3 marker (both considered as tongues of the Pine Point Formation.

places. However, since no pattern in the distribution of the dolomitized zones is apparent, and as the gross appearance of the dolomites is little different from the limestone equivalents, the dolomitized zones are here included within the member.

In subsurface the lithology varies from unfossiliferous bituminous calcilutite with wispy bituminous shaly partings and chert nodules, to bituminous fine calcarenite and medium crystalline dolomite rich in crinoids and brachiopods. Finger corals (Thamnopora) and a few large horn corals occur, usually in the dolomitized zones and in such areas the matrix is commonly a medium- to coarsely crystalline bituminous dolomite with relict grain outlines that suggest derivation from a primary sediment consisting of fine- to medium-grained sand. Carbonaceous material is usually more abundant in undolomitized zones.

The unit is very fine-grained, black, petroliferous, and argillaceous in the most northerly holes and contains abundant Lingula, Tentaculites, and thin-shelled brachiopods (Fig.A12, D.D.H. 1343 and 1344).

Norris (1965, p.51) assigned 140 feet (incomplete) of strata to the bituminous shale and limestone member. A maximum thickness of 105 feet (incomplete) of argillaceous limestone and dolomite assigned to the bituminous shale, limestone, and dolomite member was intersected in cores logged by the writer (Fig.A7, D.D.H. 1383).

Drilling control does not permit precise delineation of the member. However, cross sections (Figs.A2-A13) show that it occurs in the subsurface along the entire north side of the study area but does not extend south as far as the longitudinal section AA' (Fig.A14).

The bituminous shale, limestone, and dolomite member generally intertongues with and wedges from the north into the fine-grained

dolomite member. It overlies the fine-grained dolomite member in the Cominco G-4 well (Norris, 1965, Fig.7, Section E-F). In D.D.H. 62 (Fig.A6) the member conformably overlies the fine-grained dolomite member with a gradational contact placed at the change from medium brown (below) to dark brown (above). Elsewhere the lower contact is not intersected by drilling.

The bituminous shale, limestone, and dolomite member passes laterally southward into the fine-grained dolomite member with both gradational and intertonguing relationships. Where the lithology is dolomite, the contact is defined by colour change, and strata are assigned to the bituminous shale, limestone, and dolomite member if dark brown, and to the fine-grained dolomite member if medium to light brown.

At least three different overlying units are in contact with the bituminous shale, limestone, and dolomite member:

1. The fine-grained dolomite member of the Pine Point Formation e.g. D.D.H. 62 (Fig.A12); gradational contact placed at the top of the dark brown dolomite overlain by medium brown dolomite.
2. Brown limestone of the Buffalo River Formation e.g. D.D.H. 1344 (Fig.A12), Cominco G-4 (Norris, 1965, p.53 and Fig.7); gradational contact in D.D.H. 1344, with top placed at the colour change from dark brown to medium brown.
3. Coarsely crystalline dolomite of the Presqu'ile Formation e.g. D.D.H. 1381 and 1382 (Fig.A6); sharp and gradational contacts between finely crystalline dark brown dolomite and the overlying coarsely crystalline dolomite. The contact is placed at the base of the lowest occurrence of coarsely crystalline light brown dolomite.

The most widespread relationship is the gradational contact with the fine-grained Pine Point dolomite.

Fine-grained Dolomite Member

The fine-grained dolomite member consists mainly of finely crystalline to aphanocrystalline generally porous dolomite, friable medium to finely crystalline dolomite with good intercrystalline porosity, and finely crystalline massive dolomite with some vuggy porosity. Campbell (1950, p.93) described two beds of green shale and argillaceous dolomite from 85 feet above the base of the fine-grained dolomite member and designated them as the E-2 (lower) and E-1 (upper) horizons (see Norris, 1965, Fig.7). Holes logged for the thesis are too shallow to intersect these beds.

The thickest section intersected is in the Cominco Test G-1 well where 460 feet of finely crystalline dolomite overlies Norris' lower limestone member of the Pine Point Formation and is overlain by coarsely crystalline dolomite of the Presqu'ile Formation (Norris, 1965, Fig.7). The (459.7-foot thick) section from 132.6 to 592.3 feet in the Cominco G-1 well was designated by Norris (1965, p.57) as the type section of the fine-grained dolomite member.

Norris (1965, Fig.7) divided the member into three map units based on lithology. In this study subdivisions of the fine-grained dolomite member are discussed in the section on facies analysis.

The fine-grained dolomite member underlies most of the study area as seen in sections A2-A14 and outcrops in the eastern part of the area (Norris, 1965, Fig.7). In the Cominco G-4 well the fine-grained dolomite forms the basal member of the Pine Point Formation and lies between the Chinchaga Formation (below) and the bituminous shale,

limestone, and dolomite member (above) (Figs.4 and 5; Norris, 1965, Fig.7). The upper contact is gradational and is placed at the change from dolomite to limestone.

The fine-grained dolomite grades to and intertongues with both the 'bituminous shale, limestone, and dolomite member' and the Buffalo River Formation to the north (Figs.A2, A6, A7, and A12). To the south, just beyond the study area, the fine-grained dolomite member 'appears to grade or interfinger with evaporites of the lower part of the Nyarling Formation' (Norris, 1965, p.56). In the southern part of the study area, the fine-grained dolomite member grades to or intertongues with the lower part of the Presqu'ile Formation (Fig.A11).

The upper contact with the Presqu'ile Formation is sharp where the D3 marker (the uppermost bed of the Pine Point Formation) is present and is placed at the top of the brecciated finely crystalline dolomite of the D3 marker. This marker extends over only part of the study area (see Fig.A1) and where it is absent the contact between the fine-grained dolomite member and the very coarsely crystalline dolomite of the Presqu'ile Formation is sharp or gradational. It is placed arbitrarily at the change from medium-brown dolomite with sparse white sparry dolomite (below) to buff and grey coarsely crystalline dolomite with abundant white sparry dolomite (above). Interbedding of the fine-grained dolomite member with the Presqu'ile dolomite is common in the western part of the study area and the contact cannot be established precisely. To the immediate south of the study area, the fine-grained dolomite is in sharp contact with the overlying white limestones of the Sulphur Point Formation.

D3 Marker Bed

Along the southern side of the study area a bed of finely

crystalline, bluish grey dolomite, fractured dolomite, and dolomite breccia separates the Presqu'ile Formation from the underlying Pine Point Formation and is traditionally considered by Pine Point Mines' geologists to be the basal bed of the Presqu'ile Formation. It is grouped here with the Pine Point Formation. It averages 20-30 feet thick over much of the area (see cross sections) but wedges to zero near the central part of the study area along a line trending east-northeast (Fig.A1). It reaches up to 100 feet but where this thickness occurs it does not always exhibit the typical brecciated appearance and may be confused with finely crystalline, compact, bluish-grey dolomite of the fine-grained dolomite member of the Pine Point Formation. It is recognized and logged partly by stratigraphic position.

The areal distribution of the D3 bed is shown on Fig.A1 and the thickness distribution on the cross sections (Figs.A2-A14). The northern margin of the unit trends east-northeast. Toward the western part of the study area it occurs only sporadically and it is questionable whether the unit can be differentiated to the west of X line (Fig.A9).

The D3 bed usually has some vuggy porosity between breccia clasts and frequently contains abundant white sparry dolomite (Fig.3:3), though this is not typical. Finely disseminated marcasite along fractures and within the rock frequently gives the rock a 'blue veined' and bluish-grey appearance. Breccia clasts are sometimes distinct and remnants of corals and stromatoporoids are commonly recognizable. Bryozoans are said to occur (Norris, 1965, p.57). The clasts are sometimes rotated from their original position but more commonly little or no indication of original bedding is present. Marcasite, pyrite, galena, and sphalerite crystals are common in vugs and along fractures. In particular, long

needle-like crystals of marcasite typically occur in the vugs.

C Marker Beds

About the middle of the Presqu'ile section is a distinctive bed or beds of buff or brown, medium to finely crystalline, porous dolomite. Areal distribution closely parallels that of the D3 bed, but it extends more continuously over the study area. The marker consists of one bed toward the south (Figs.A2-A14) which usually splits into two and sometimes three thin beds, all of which wedge gradually to zero slightly north of the central part of the Presqu'ile Formation (Figs.6, A1).

Where there is only one layer, it is usually about 10 feet thick; but where 2 or 3 layers occur, they are 1-5 feet thick, separated by 5-10 feet of very coarsely crystalline dolomite. The thickness of the main unit varies considerably in the western area and reaches from 25-30 feet in F and Z sections (Figs.A3 and A5). However, it is very thin in the adjacent section Z5E and occurs in only two holes.

In section D (Fig.A11) the C marker is demonstrated to be a lateral wedge of the fine-grained dolomite member of the Pine Point Formation. The C markers and the Pine Point Formation are presumed to have this relationship to the south of the study area. The markers are thus grouped as tongues of the Pine Point Formation, though drill hole data do not extend far enough to document this relationship on other cross sections.

BUFFALO RIVER FORMATION

The name Buffalo River Formation was proposed by Campbell (1950, p.94) for a unit of green shale 100 feet thick intersected by two drill holes of the American Metals Company of Canada in the vicinity of the

mouth of the Buffalo River (see Norris, 1965, Fig.7). Campbell (1957, p.169) and Norris (1965, p.53) demoted the unit to member rank and included it in the Pine Point Formation. Norris redefined the upper boundary to include some 7 feet of brown limestone and 13.4 feet of bluish-green shale and designated the type section as the 185.4 feet in the interval 172.6 to 358 feet in the Cominco Test G-4 well.

Subsequent to Norris' work a number of drill holes have penetrated the shales along the northern side of the study area and the distribution of the Buffalo River unit is now better known. The general relation of this member to other units is shown in Fig.5. In holes logged for this study, this member attains maximum thickness of 150 feet (complete?) in D.D.H. 1343 (Fig.A12).

Norris established that the Buffalo River unit is roughly equivalent to the upper part of his fine-grained dolomite member of the Pine Point Formation (Norris, 1965, p.53). It is now evident that the unit is equivalent to the lower part of the Sulphur Point and Presqu'ile Formations, and the fine-grained dolomite member of the Pine Point Formation--that is, nearly all the carbonate units below the Amco marker. The Buffalo River is therefore reinstated as a Formation. If the type section (containing carbonates) of Norris (1965) is used, then the division between the Buffalo River Formation and the pure carbonate units becomes arbitrary since, as seen in Figs.A2, A6 and A12, the shale intertongues with the carbonates along the north side of the carbonate accumulation. In this setting, the strata between the top of the uppermost green shale and the base of the lowermost green shale are assigned to the Buffalo River Formation if the section contains over 50 percent shale.

The lower contact of the Buffalo River Formation with the bituminous shale, limestone, and dolomite member in D.D.H. 1344 (Fig.A12) is gradational and is placed at the colour change from dark brown (below) to medium brown (above). In the Cominco G-4 well, the lower contact is placed at the change from shale (above) to argillaceous limestone of the bituminous shale, limestone, and dolomite member (below) (Norris, 1965, p.53).

The upper contact with the Sulphur Point Formation is gradational and is placed at the top of the uppermost green shale bed e.g., D.D.H. 1344 (Fig.A12).

PRESQU'ILE FORMATION

A very coarsely crystalline dolomite unit which immediately overlies the Pine Point Formation in most of the study area was termed the Presqu'ile Formation by Cameron (1918, pp.25-26). He proposed the name for strata exposed at Presqu'ile Point and Burnt Islands near Dawson Landing on the south shore, and Windy Point on the north shore of Great Slave Lake. In 1922 he included a considerable variety of dolomites and limestones within this unit, including various facies of the Pine Point Formation as it is now defined.

Campbell (1957, p.168) and Norris (1965, p.64) restricted the Presqu'ile to include only the very coarsely crystalline upper part of the dolomites between the Chinchaga Formation and the Slave Point Formation. Norris (1965) did not designate a type section for the Presqu'ile Formation but restricted the formation to include 'mainly a light coloured coarsely crystalline variable vuggy massive dolomite which is generally presumed to have replaced reefal limestone. He excluded the various interfingerings and gradations of undolomitized 'reefal'

limestone and associated limestone facies and placed them in the Sulphur Point Formation. The Presqu'ile Formation is thus diagenetic in origin but does reflect an original sedimentary unit to a great extent.

The main outcrop area of this formation in the study area is between one and two square miles in extent and lies about 9 miles southeast of Presqu'ile Point on the south side of Great Slave Lake. However, open pit mining in the vicinity of Pine Point town has exposed almost the entire Presqu'ile section (composite from several pits). These exposures are superior to any natural outcrop of the formation and data obtained from these exposures and from diamond drill cores are given priority in this study. Outcrop data has been presented by Norris (1965) and earlier workers.

The very coarsely crystalline vuggy dolomites of the Presqu'ile Formation are very distinctive in the study area, (see Plates 1-4). The Presqu'ile Formation (Fig.6) reaches a thickness of about 230 feet in the central part and wedges southward within fine-grained dolomite (below) and limestone (above) that in turn pass into evaporites of the Nyarling Formation farther south. To the north it pinches out within fine-grained dolomite and shaly bituminous limestone beds of the Sulphur Point Formation that in turn pass into shale of the Buffalo River Formation. Since differing stratigraphic levels are involved, thickness variations are complex but along strike the interval between the C markers and the Amco marker can be measured with some accuracy. This interval varies in thickness from 190 feet in the Buffalo River area to 130 feet fifteen miles farther east (Norris, 1965, p.74; see also section AA' (Fig.A14) in this thesis).

In the eastern part of the study area, as seen in the cross sections

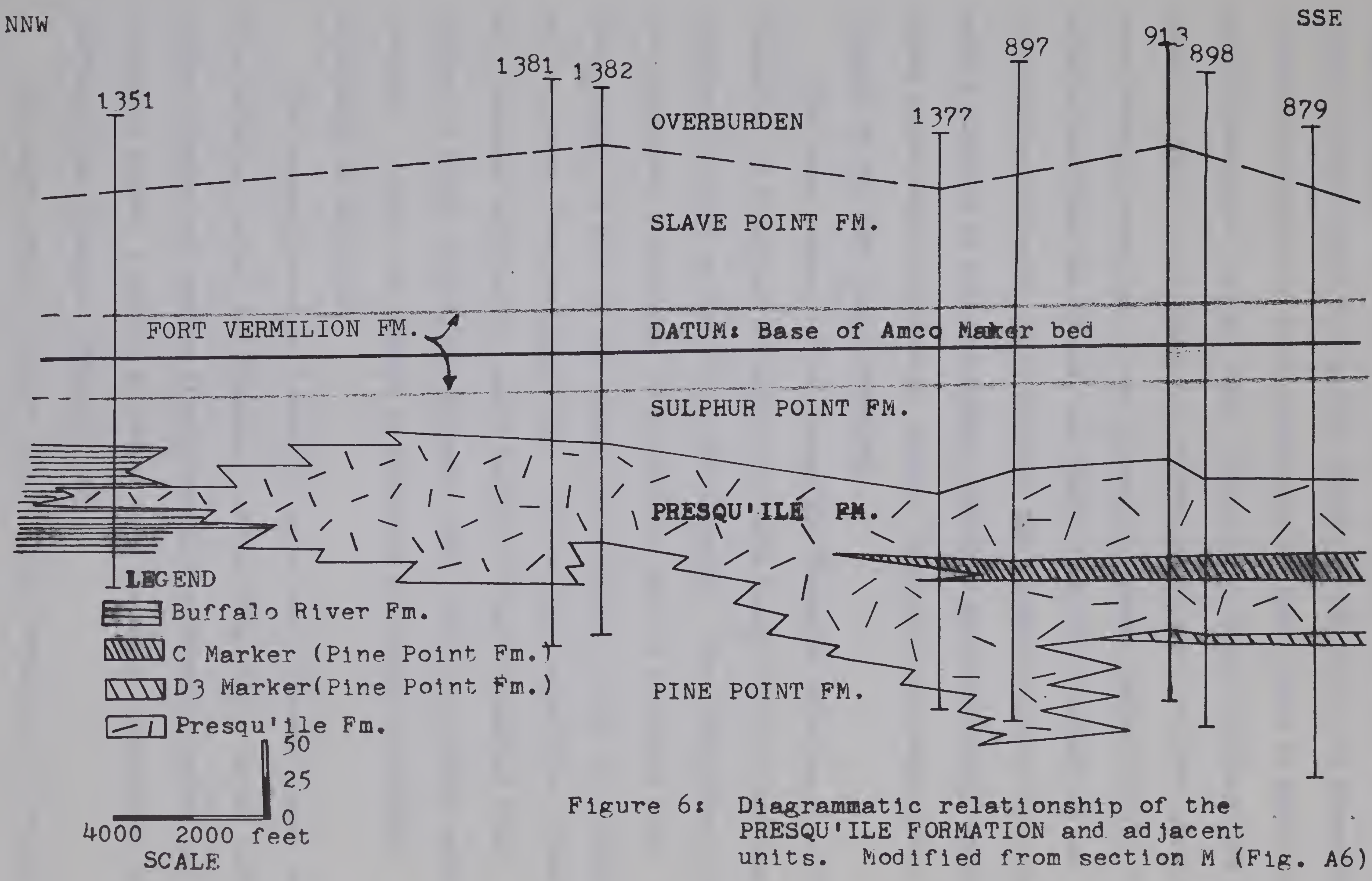


Figure 6: Diagrammatic relationship of the PRESQU'ILE FORMATION and adjacent units. Modified from section M (Fig. A6).

(Figs.A2-A14), the lower contact is marked by the top of a distinctive marker horizon termed by Campbell (1957) the D3 zone. The Presqu'ile Formation is further divided into upper and lower parts by distinctive strata termed the C marker beds. These local marker horizons have been named by Cominco geologists for reference purposes, but they have not been formally described in the literature, though Campbell (1957, Fig.1) briefly described the D3 bed, and Norris used the C markers in his illustrations (Norris, 1965, Fig.7). The C and D3 markers lie approximately parallel to the Amco marker, and they are particularly useful as datum planes where the Amco is eroded. They are both considered to be tongues of the Pine Point Formation.

The lower contact of the Presqu'ile Formation with the Pine Point Formation is irregular throughout the area except where it has been arbitrarily fixed as the top of the D3 marker. The lithologies of the two formations interfinger in the western part of the study area. In that region the base of the Presqu'ile is chosen, as far as possible, at the change from overlying buff, very coarsely crystalline dolomite with abundant milky-white sparry dolomite to dark or medium brown, medium to finely crystalline dolomite with little or no white sparry dolomite. Again, the contact is arbitrary and cannot be defined accurately in this area.

The Presqu'ile wedges laterally to the south between finely crystalline dolomite (below) and limestone (above) (Fig.A11). To the north it either pinches out between finely crystalline dolomite (below) and limestone (above, Fig.A11) or wedges into shale and limestone of the Buffalo River Formation (Figs.A6, A12).

The upper contact with the Sulphur Point Formation is irregular.

Interbedding of Sulphur Point limestone and Presqu'ile dolomite is common and the contact is arbitrary. Limestones typical of the Sulphur Point Formation, green shale (Norris' Watt Mountain Formation) are interbedded in the O42 and N42 pits immediately northeast of Pine Point townsite, causing further confusion in terminology. This relationship is also evident on some cross sections e.g. (Figs.A4, A9). The top of the Presqu'ile Formation is usually placed at the top of the very coarsely crystalline dolomite, or where limestone becomes predominant. The upper part of the Presqu'ile Formation thus contains lenses of limestone of Sulphur Point affinity.

SULPHUR POINT FORMATION

General

Norris (1965) proposed the name Sulphur Point Formation for the sequence of limestones and interbedded limestones and dolomites overlying the Pine Point Formation and in turn overlain by limestones of the Slave Point Formation or by interbedded shales and limestones of the Watt Mountain Formation. This unit is thus roughly the undolomitized equivalent of the Presqu'ile Formation. Norris designated as the type section of the formation, the sequence described as map-unit 13 by Douglas (1959, p.42) in the Cominco Test G-4 well (footage 20-172.6). The core from this well is now in poor condition due to weathering, loss of core, and footage markers. The writer proposes the establishment of a reference core. This core is from Cominco D.D.H. No. 262 (Lat.60° 45'N, Long.114° 48'W) and in it the Sulphur Point occupies the interval 178 feet (base of proposed Fort Vermilion Formation) to 284 feet (Presqu'ile Formation). It includes the Watt Mountain Formation of Norris (1965, p.72). This core is stored in the collection of the Institute of Sedimentary and

Petroleum Geology, Calgary, Alberta. A brief log is included here as Appendix B.

The only outcrop areas on the south shore are one in the vicinity of Sulphur Point and one just east of the tip of Presqu'ile Point. The maximum thickness exposed is noted by Norris (1965, p.70) as 7.5 feet.

In drill holes the Sulphur Point can be seen to interbed and interfinger with the Presqu'ile dolomite near the very irregular contact between the two units. The Sulphur Point is thus in part the undolomitized equivalent of the Presqu'ile and in general is distributed lateral to, and overlying the Presqu'ile dolomite (Fig.7). The lower contact is gradational and is arbitrarily placed at the top of the coarsely crystalline dolomite beds i.e. where they predominate over limestone.

The upper contact of the Sulphur Point Formation as defined by Norris (1965, p.68) is the base of the Slave Point Formation (which Norris arbitrarily placed at the base of the Amco marker). Where interbedded shale and limestone equivalent to the Watt Mountain Formation occur locally, the definition can be altered in order to classify a sequence of rocks lying between the Watt Mountain shale and the Amco marker where both are present.

The Watt Mountain shale and limestone is considered in this work, as in Norris (1965, Fig.3), to be a facies within the Sulphur Point Formation rather than a separate formation. However, the strata between the Watt Mountain shale and the Amco marker are recognized as part of the Fort Vermilion Formation and are excluded from the Sulphur Point Formation.

The Sulphur Point Formation contains four main lithologies:

1. Massive, cream coloured limestone.

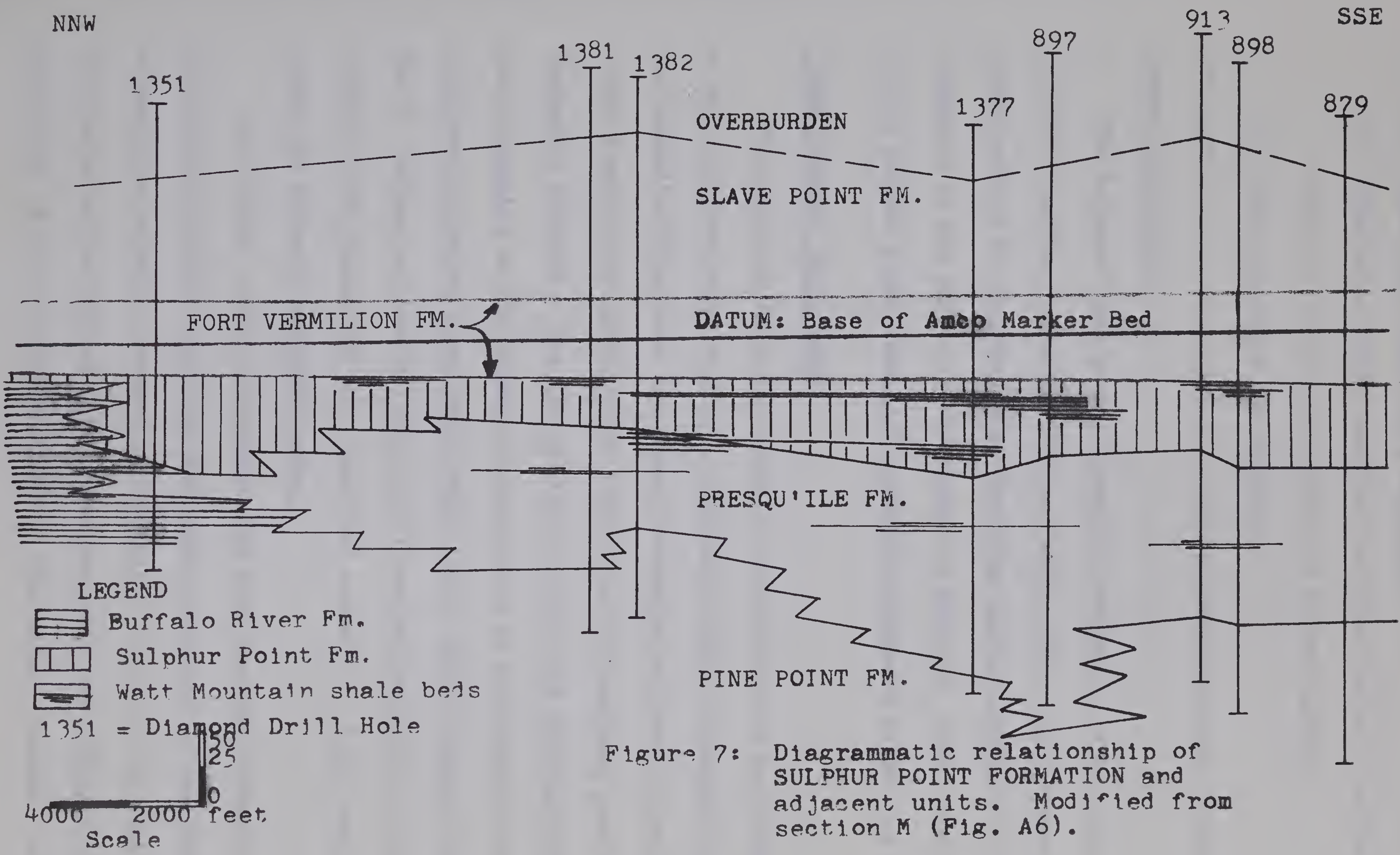


Figure 7: Diagrammatic relationship of SULPHUR POINT FORMATION and adjacent units. Modified from section M (Fig. A6).

2. Green waxy shale (Watt Mountain).
3. Gypsiferous white limestone and green shale; interlaminated finely crystalline dolomite and gypsum (sabkha).
4. Brown limestone and dolomite.

The section on facies analysis describes the nature and relationships of these lithologies.

The Sulphur Point grades laterally southward, beyond the study area, into the Nyarling Formation (Norris, 1965, p.65). To the north the lower part of the Sulphur Point Formation passes laterally to shale and limestone of the Buffalo River Formation (Figs.A6, A12). The upper part of the Sulphur Point Formation continues northward beyond the study area.

"<u>Watt Mountain Shale Beds</u>"

The name Watt Mountain Formation was proposed by Law (1955a,b) for a unit 155 feet thick of shale, siltstone, arkose, limestone breccia, and dolomite lying above the Muskeg Formation and overlain by the Slave Point Formation of northwestern Alberta and the southern part of the Mackenzie District. The type section for the Watt Mountain Formation was designated as the interval from 4,454.5 to 4,513 feet in the California Standard Steen River well (Lsd.2, Sec.22, Twp.117, Rge.5, W6 Mer.). Belyea and Norris (1962, p.12) revised the unit to exclude the Sulphur Point limestones and placed the contacts at 4,455 and 4,488 feet depths in the well mentioned above.

Law (1955b, p.1951) correlated the Watt Mountain Formation with the Amco marker and beds below the Amco down to the top of the coarsely crystalline dolomite (Presqu'ile Formation). This is the same interval designated as the Sulphur Point Formation by Norris (1965, p.68) whose definition is more closely followed in this study. However, within

this interval are a number of green, waxy shale beds separated by white limestones. The shales are usually less than a foot thick but sometimes reach 8 to 10 feet in thickness in cores (D.D.H. 1415, Fig.A10). The shale beds occur within as much as 140 feet of section (D.D.H. 185, Fig.A10) and vary in number and thickness. They frequently cannot be correlated between holes only 1,000 feet apart (Fig.A2-A10). In order to maintain a consistent nomenclature and considering the sporadic nature of distribution of the shales, the "Watt Mountain" shales and interbedded limestones are considered part of the Sulphur Point Formation. Hereafter these shales are termed the bright-green shale facies.

FORT VERMILION FORMATION

General

A sequence of anhydrite, dolomite, and laminated vuggy limestone occupies the interval from the top of the bright green shale facies of the Sulphur Point Formation to some 35 feet above the Amco marker bed that was considered by Norris (1965, p.75) as the base of the Slave Point Formation. The evaporites are well developed in this unit in D.D.H. 1384 (Fig.A7), but do not occur in many holes. However, the distinctive laminated vuggy limestones, dolomitic limestones and compact mottled dolomites serve equally well to delimit this unit throughout the study area (e.g. Figs.A6 and A7).

This sequence is probably the correlative of the Fort Vermilion Formation (Table 2). Law (1955a, p.1945) introduced the term Fort Vermilion Member of the Slave Point Formation for 120 feet of anhydrite and dolomite at the base of the Slave Point Formation. Norris (1963, p.59) raised the Fort Vermilion Member to formational rank. The type

section is in Hudson's Bay Ft. Vermilion No. 1 well (Sec.32, Twp.102, Rge.8, W.5 Mer.) from 2300 to 2420 feet.

The Fort Vermilion Formation is recognized between 105 and 178 feet (73 feet thick) in the local reference section used for this study (Hole 262, Appendix B). Recognition of this unit can help solve the problem of correlating with other areas (see Fishbuch and Leavitt, 1968).

Preliminary results from carbon and oxygen isotope studies have indicated that the Fort Vermilion dolomites have a distinct oxygen isotope content and $CaCO_3$ content when compared with the underlying dolomites (see Appendix F for data and brief discussion). The isotopic and chemical composition may be features useful for the recognition and correlation of the Fort Vermilion Formation. Research is continuing in this field.

The Amco Marker

The Amco marker bed was defined by Campbell (1957) from diamond drill holes drilled immediately west of the mouth of the Buffalo River (Fig.A1) by the American Metals Company of Canada (hence the name Amco). It is a uniform 10-11-foot bed of grey argillaceous, dolomitic limestone which usually exhibits a good shaly parting (Figs.A2-A10). It is similar in appearance to shales and argillaceous limestones of the Buffalo River Formation and may be regarded as a tongue related to this unit. This may be seen where shales and limestones of the Buffalo River Formation occur immediately below the Amco; as, for example, on the northern end of section M (Fig.A6).

While Norris (1965, p.75) arbitrarily placed the Amco marker bed within the Slave Point Formation, it is considered here to be part of the Fort Vermilion Formation.

SLAVE POINT FORMATION

General

Cameron (1918, p.25-26) proposed the name Slave Point limestones for the upper part of the Middle Devonian section outcropping along the south side of Great Slave Lake from Presqu'ile Point to High Point, along the Buffalo River, and on the north shore between House and Moraine Points. Subsequently, Cameron (1922) revised the Slave Point Formation of the south shore of Great Slave Lake to include only the rocks exposed in the vicinity of Sulphur Point and along the Buffalo River. Later still, Campbell (1957) again redefined the Slave Point Formation as the interval between the base of the Hay River Shale and the top of the uppermost Charophyta zone in the Presqu'ile Formation. However, the occurrence of the Charophyta zone is not easily established due to the erratic occurrence of the bright-green shale facies containing the charophytes. Because of this, Norris (1965, p.75) arbitrarily selected the base of the Slave Point at the base of the Amco marker. The lower contact is considered here to be at the top of laminated vuggy limestones, tan mottled with grey dolomites and interlaminated anhydrite and dolomite of the Fort Vermilion Formation. This contact cannot be accurately defined and is arbitrary. Figure 7 gives a generalized representation of the Slave Point Formation.

Petroleum geologists, for subsurface definition of the base of the Slave Point, use the top of a characteristic low self potential response and high gamma ray 'kicks' which correspond to the bluish green waxy shale zone described previously as the bright green shale facies of the Sulphur Point Formation. This places the lower contact in subsurface about 30-50 feet below the base of the Amco or i.e. at the base of the

Fort Vermilion Formation.

Apart from the basal beds, the Slave Point Formation has not been examined in detail in this study. Up to 175 feet thick, the formation consists of interbedded finely laminated micrites, biosparites, and lesser intrasparite. Some of the beds contain conspicuous subspherical stromatoporoids. Rarely, a layer of coarsely crystalline white dolomite occurs above the Amco marker (Fig.A6, D.D.H. 1350 and 1351) in the basal part of the Slave Point Formation.

CHAPTER 3: PALEOECOLOGY AND FACIES ANALYSIS

GENERAL

The carbonate complex in the Pine Point area has been variously referred to as:

1. "barrier reef" (Law, 1955a,b)
2. "reef complex" (Campbell, 1957, p.164)
3. the "Presqu'ile Barrier Reef" (Grayston, Sherwin and Allan, 1964, Fig.5-11D)
4. "facies front" (Griffin, 1965, p.7)
5. "carbonate edge," "barrier edge" (Bassett and Stout, 1967, p.738, 739).

Severe dolomitization characterizes the entire Pine Point-Presqu'ile interval and in consequence it is necessary to rely heavily on detailed studies and interpretations of facies and paleoecology of analagous, but much better preserved limestone accumulations. Paleoecological interpretations of these dolomitized carbonates are thus much more subject to doubt than those on limestones, but significant conclusions can be reached.

A major objective of this investigation was to attempt to determine whether the carbonate complex accumulated as a reef-controlled barrier. Organisms such as stromatoporoids, with the ecologic potential to build reefs, were recognized by earlier workers but no data were available to indicate whether the organisms formed structures that might reasonably be interpreted as reefs. However, the poor preservation of fossils in the rocks of the study area made the objective establishment of detailed biosomes impossible. Despite this difficulty, an attempt was made to obtain an impression of the overall distribution of various fossils in

relation to the complex lithofacies pattern at Pine Point. The distribution of both fossils and lithofacies is shown on the maps and charts and an admittedly rather subjective interpretation is attempted.

FOSSILS--GENERAL DISTRIBUTION AND INTERPRETATION

On a regional basis, fossils are abundant in many parts of the carbonate complex but in the dolomitized zones only some types persist as relict outlines and molds. Taxonomic grouping of the fossil outlines is difficult but a designation to phylum level is usually possible. Specific identifications are not possible for the bulk of the material used. However, as most of the fossil assemblages are believed to be environment controlled, it was not anticipated that they could be used for detailed correlation, and for the present study the lack of identifications at the specific level is not unduly restrictive.

The various types of fossils identified are listed in Table 3 and an account of their individual paleoecological significance as interpreted by previous workers is given in Appendix C.

The areal occurrence of each of these forms is plotted on Figs. A15-A17 for each of the Pine Point, Presqu'ile, and Sulphur Point Formations. The distributions are summarized on Figs.8 to 10. Rather than showing the distribution of the fauna along a hypothetical time line, these plots show the distribution of fauna during the interval of time required to deposit the particular formation. As the recognizable preservation of fossils is sporadic, even within units that are probably largely biogenic, the detailed stratigraphic level of their recognition was not considered to be as significant as <u>the fact</u> of <u>their occurrence within a given lithofacies</u>. Accordingly, most occurrences of fossils are intentionally plotted, regardless of stratigraphic level within the

formation. These plots are affected by three major factors:

1. The variable amounts of stratigraphic coverage in holes from the Pine Point Formation
2. The lateral equivalence of the Presqu'ile and Sulphur Point Formations in places
3. The transportation of fossil material from growth sites--plots are made considering all material, whether whole or fragmented, that is recognizable in hand specimen

Regardless of this bias, consideration of the areal distribution of fossils as shown on Figs.A15-A17, in conjunction with their distribution in section (Figs.A2-A14), allows generalizations to be made regarding the faunal distribution during the deposition of each formation.

The Pine Point Formation (Fig.A15) is characterized by four belts trending east-northeast:

1. a _Lingula_-Tentaculitid belt at depth to the extreme north
2. a belt with _Thamnopora_, crinoids, thin-shelled brachiopods, and chert nodules (sponge silica?) overlapping and to the south of 1
3. a belt with presumed algal laminites and _Amphipora_ along the southern side of the drilled area (zone 4, Fig.A15)
4. a belt with sparse fossil remains between belts 2 and 4 (zone 3, Fig.A15)

Occurrences of subspherical and tabular stromatoporoids appear to be scattered but the most concentrated accumulations lie along the southern side of belt 2.

TABLE 3: LIST OF FOSSIL GROUPS FROM THE PRESQU'ILE CARBONATE COMPLEX, PINE POINT AREA, DISTRICT OF MACKENZIE.

FOSSIL	RELATIVE ABUNDANCE
STROMATOPOROIDS	
subspherical (massive)	rare
platy or tabular	rare
Stachyodes (dendroid)	rare
Amphipora (dendroid)	abundant
CORALS	
Thamnopora	common
rugose (horn) corals	rare
other colonial corals	rare
BRACHIOPODS	
thick-shelled, mainly *Stringocephalus*	rare
thin-shelled, not subdivided	abundant
chitino-phosphatic, *Lingula*	common
GASTROPODS	
not subdivided	rare
CRINOIDS	
mainly as individual ossicles	abundant
OSTRACODS	
not subdivided	common
ALGAE	
oncolites and micrite coatings	rare
green and blue-green algae (presence inferred from laminites)	abundant
calcispheres	common
Charophytes	common in bright-green shale facies
TRILOBITES	very rare
MISCELLANEOUS FOSSILS	
Tentaculitids	common
trace fossils such as worm burrows	common

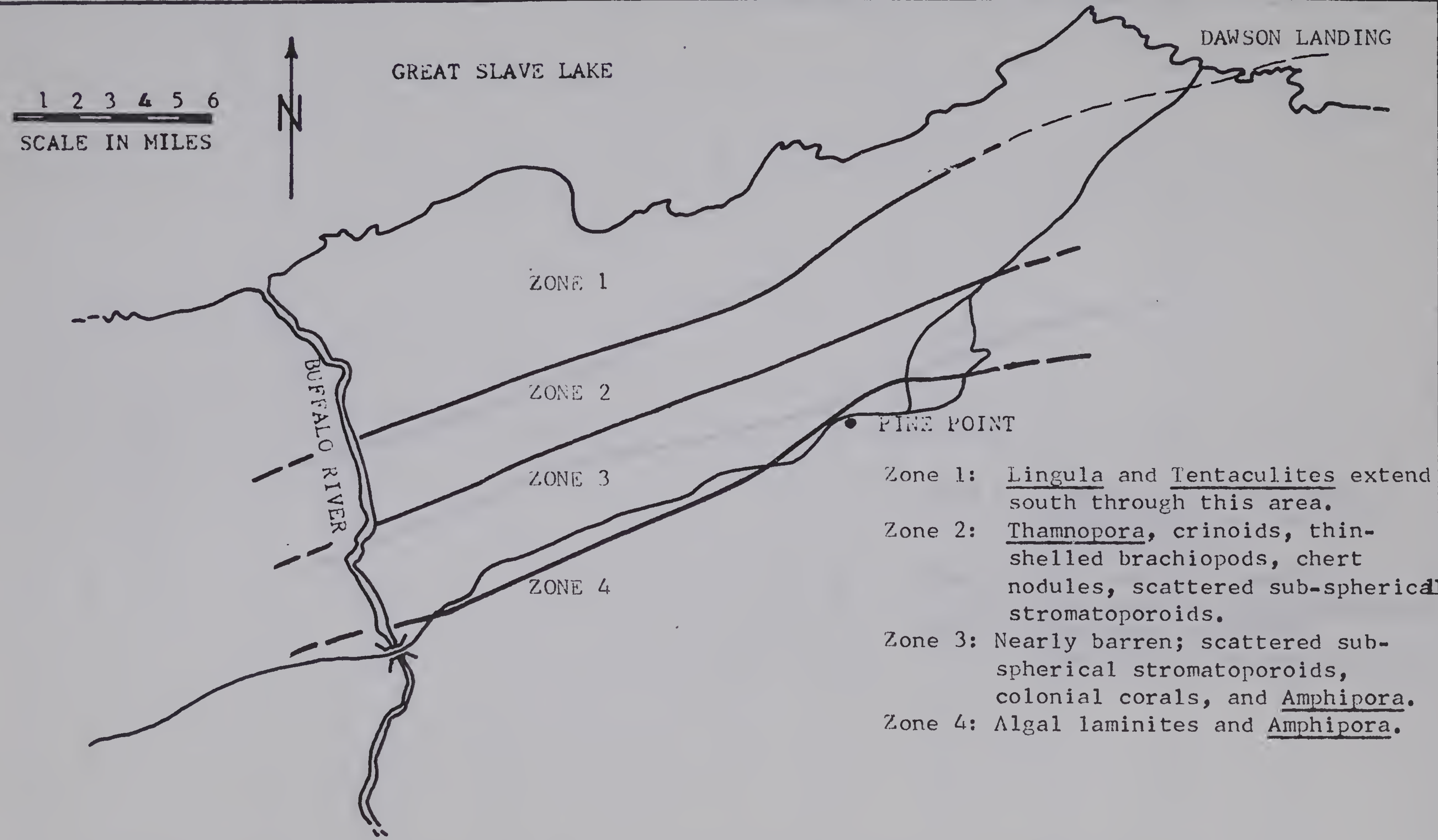


FIGURE 8: PINE POINT AREA. GENERALIZED FOSSIL DISTRIBUTION DURING PINE POINT DEPOSITION. FOR DETAIL AND CONTROL SEE FIGURE A15.

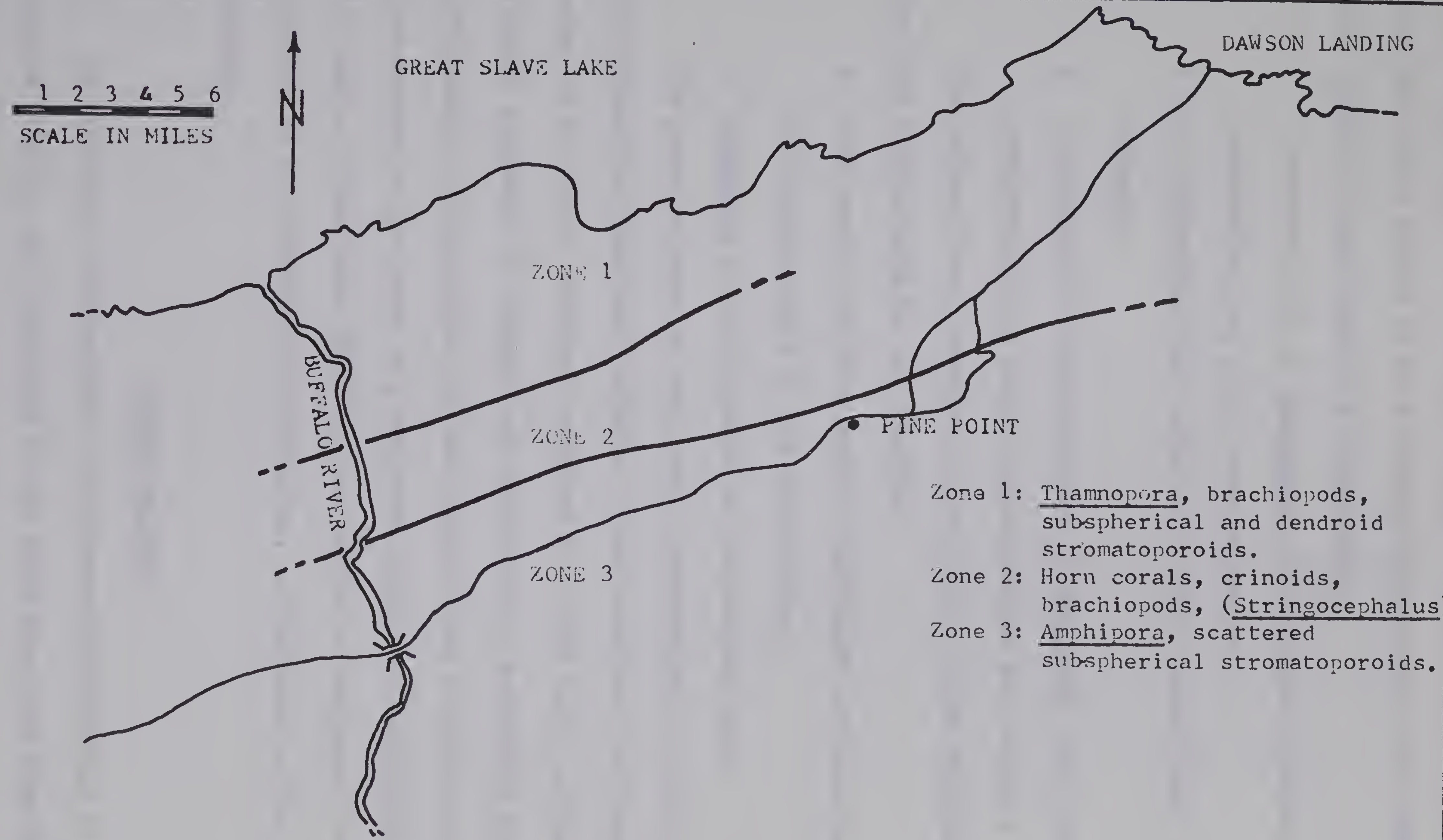


FIGURE 9: PINE POINT AREA. GENERALIZED FOSSIL DISTRIBUTION IN THE PRESQU'ILE FORMATION. FOR DETAILS AND CONTROL SEE FIGURE A16.

The Presqu'ile Formation (Fig.A16, Fig.9) is more coarsely crystalline and fossil detail is more severely obliterated, but three, less well defined, faunal belts are recognizable:

1. a northern belt of <u>Thamnopora</u>, thin-shelled brachiopods, subspherical and platy stromatoporoids
2. an intermediate belt with horn corals, brachiopods, and some crinoids
3. a southern belt characterized by <u>Amphipora</u>, with scattered subspherical and platy stromatoporoids and colonial corals

The Sulphur Point Formation (Figs.A10-A17) lacks well-defined belts but some generalizations are possible:

1. Horn corals and thin-shelled brachiopods are more common in the northern part of the drilled area
2. <u>Amphipora</u> are more common in the southern part

The gross patterns of the faunal distributions for the Pine Point and Presqu'ile Formations indicate a depth zonation from deeper basinal water to the north, shoaling southward to a surf zone, and passing farther southward to lagoonal and intertidal to supratidal areas. The environments of deposition for the Sulphur Point Formation varied from open marine to the north to a sheltered lagoon and restricted lagoon to the south. These gross distributions provide a background for the subdivision of the strata into lithofacies, as discussed in the following section.

FACIES ANALYSIS

By combining lithology with the inferred paleoecology of the various fossils, the formations of the study area have been broken into fourteen lithofacies, as listed in Table 4. Nine sub-facies believed to

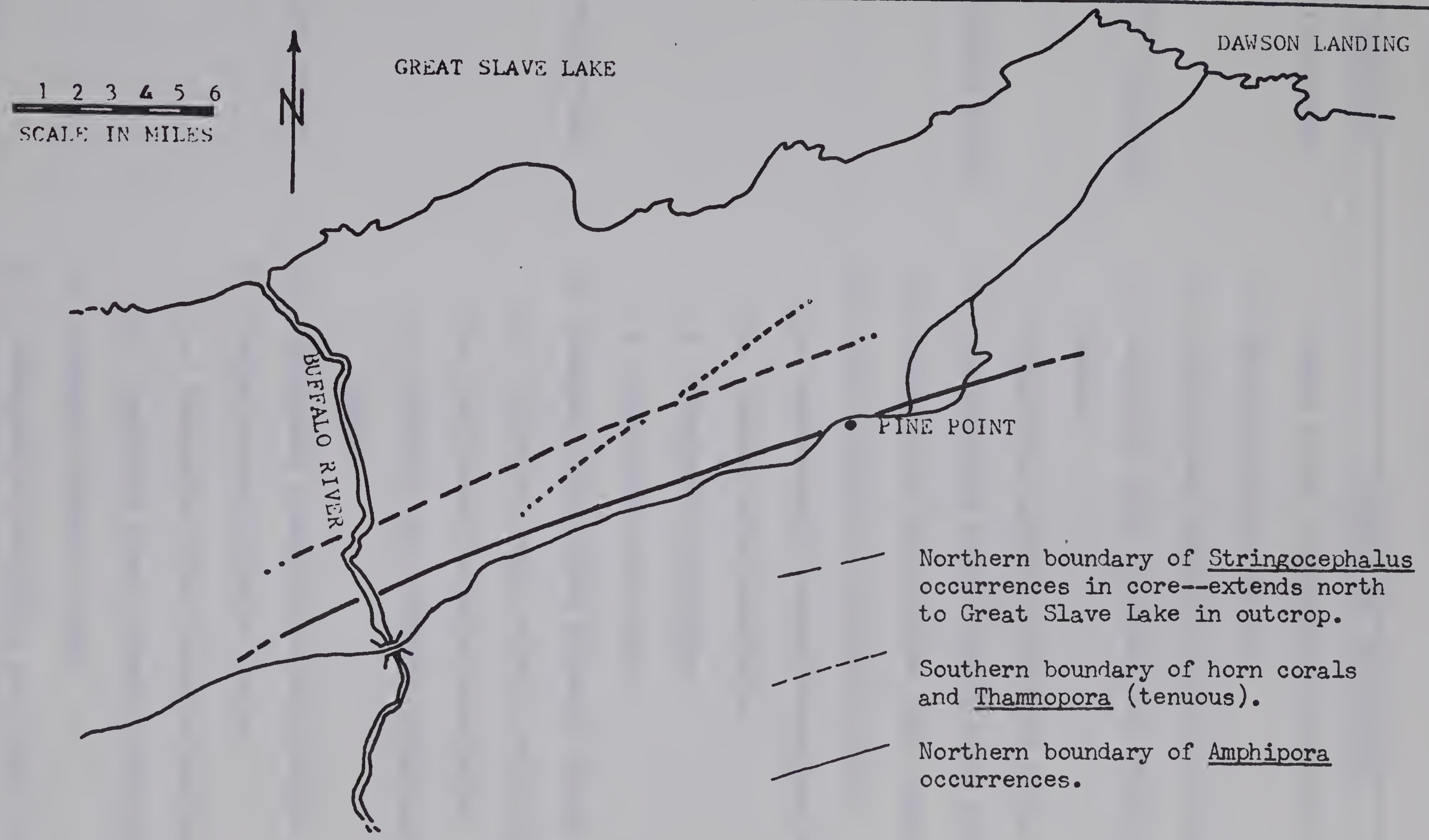


FIGURE 10: DISTRIBUTION OF RECOGNIZABLE FOSSILS IN THE SULPHUR POINT FORMATION. FOR DETAILS AND CONTROL SEE FIGURE A17.

TABLE 4: LITHOFACIES OF THE STUDY AREA

FORMATION	FACIES AND SUB-FACIES
SLAVE POINT	1. Bedded brown, fine-grained limestone facies
	2. Mottled dolomite facies
	3. Argillaceous dolomitic limestone facies (Amco)
FORT VERMILION	4. Laminated brown limestone and mottled dolomite facies
	5. Gypsiferous limestone/dolomite facies
SULPHUR POINT	6. Non-laminated brown limestone and dolomite facies
	7. Bright-green shale facies (Watt Mountain)
	8. White biosparite-pelsparite facies
	a. whole-fossil biosparite-pelsparite sub-facies
	b. biosparrudite sub-facies
	c. biosparite sub-facies
	d. pelsparite sub-facies
PRESQU'ILE	9. Coarsely crystalline dolomite facies
	a. laminated vuggy dolomite sub-facies
	b. latticework dolomite sub-facies
	c. dolomite with anhydrite pseudomorphs sub-facies
PINE POINT	10. Bituminous limestone/dolomite facies
	11. Friable brown dolomite facies
	a. bioclastic brown dolomite sub-facies
	b. laminated brown dolomite sub-facies
	12. Cohesive dolomite facies
	13. Coelenterate biolithite and rubble facies
BUFFALO RIVER	14. Dark green shale facies

be useful in genetic interpretation have been subdivided from three of the facies. Their distribution in cross section is shown on Figs.A2-A14. The areal distribution of those facies which do not blanket the study area is shown on Figs.11-13 and A18.

As the formational boundaries are based to a great extent on facies boundaries, the formation in which each facies most commonly occurs is indicated. A number of facies and rock types are based mainly on diagenetic features; but these, in turn, almost certainly reflect original differences in lithology. A description and interpretation of each facies, beginning with the oldest units, follows.

Bituminous Limestone/Dolomite Facies

The limy part of this facies consists of black, tight, fossiliferous, bituminous, argillaceous micrite containing abundant Lingula and Tentaculitids with some bituminous shaly partings. The fossils lie parallel to the bedding but are randomly oriented on the bedding surfaces. This unit was intersected in only a few drill holes (Figs.A7, A10, and A12). It lies in a belt along the northern margin of the study area (Figs.11, A18) and intertongues with the dolomitic part of the facies described below. These limy rocks are interpreted to have been deposited below wave base. The abundance of bituminous material and the restricted fauna of Lingula and Tentaculitids indicate a muddy, possibly reducing environment.

Intertonguing with the limy part of the bituminous limestone/dolomite facies on the south side is a unit characterized by abundant crinoid ossicles, thin-shelled brachiopods (Figs.5:1, 5:2)* and Thamnopora.

* Abbreviated designation used for illustration in all plates e.g. Plate 5, Fig.1 = Fig.5:1.

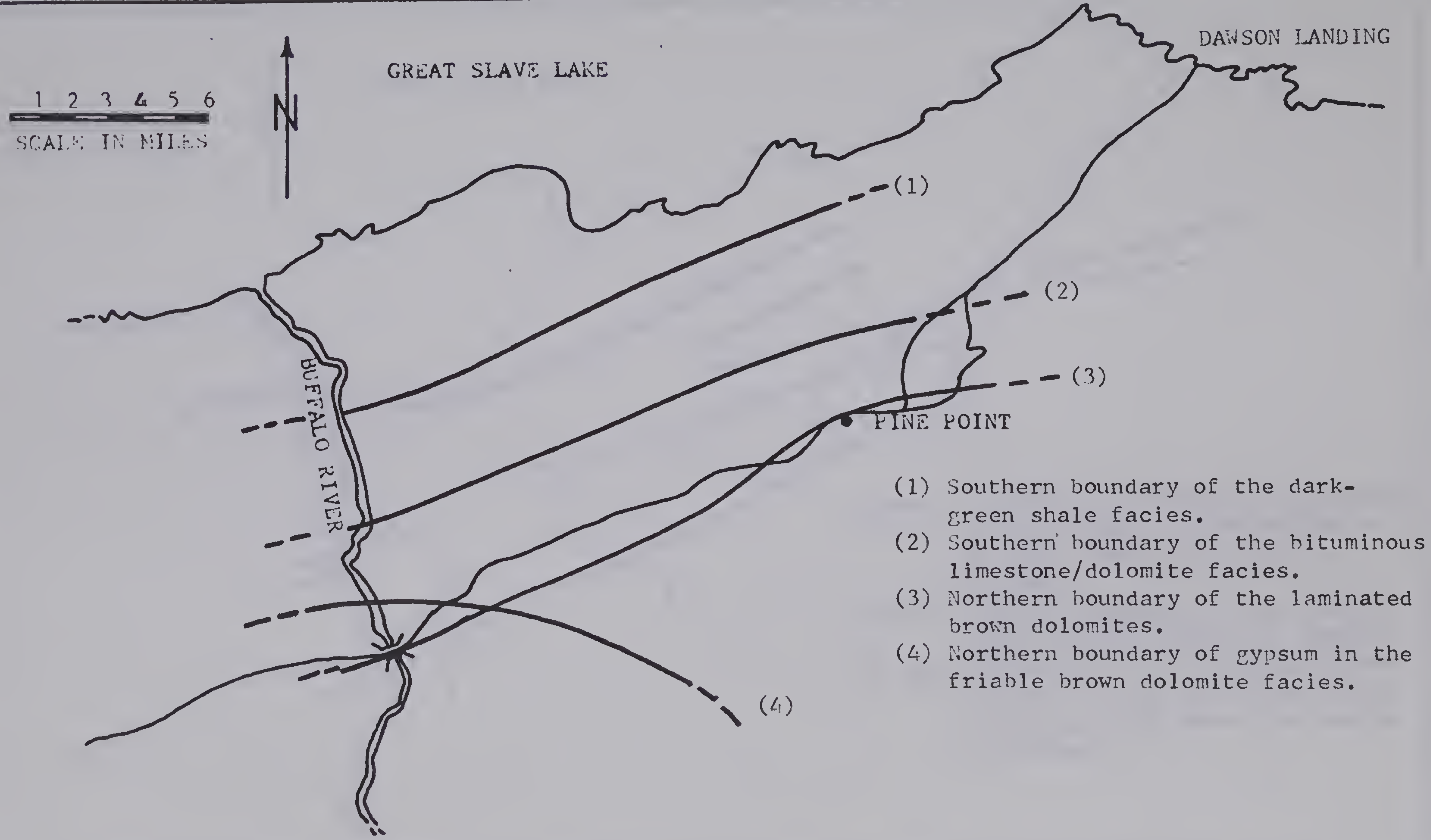


FIGURE 11: PINE POINT AREA: GENERALIZED DISTRIBUTION OF SOME FACIES AND ROCK TYPES IN THE PINE POINT FORMATION. FOR DETAIL AND CONTROL SEE FIGURE A18.

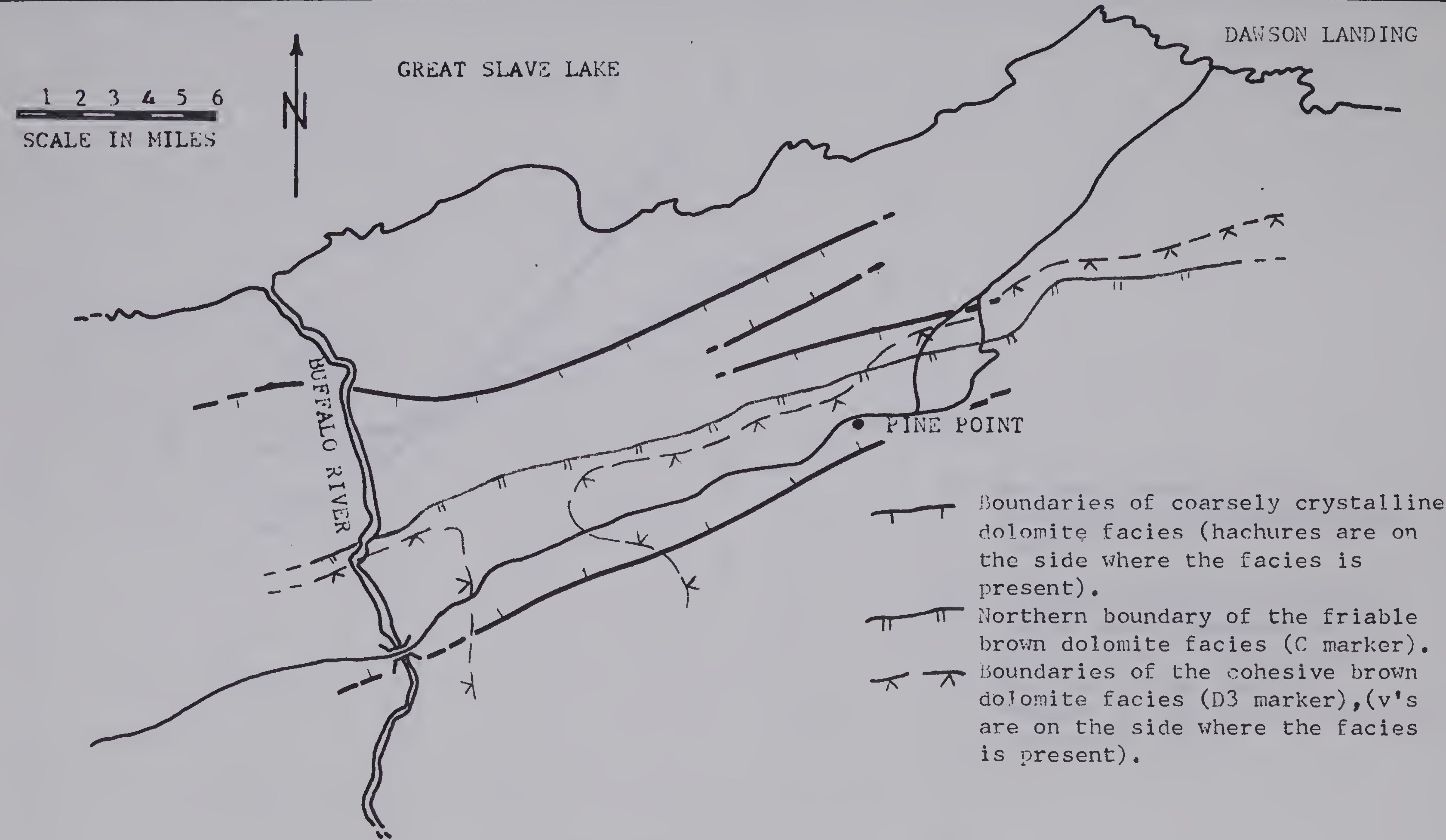


FIGURE 12: PINE POINT AREA. GENERALIZED DISTRIBUTION OF FACIES IN THE PRESQU'ILE FORMATION. SEE FIGURE A18 FOR DETAIL AND CONTROL. D_3 AND C MARKERS ARE TONGUES OF THE PINE POINT FORMATION.

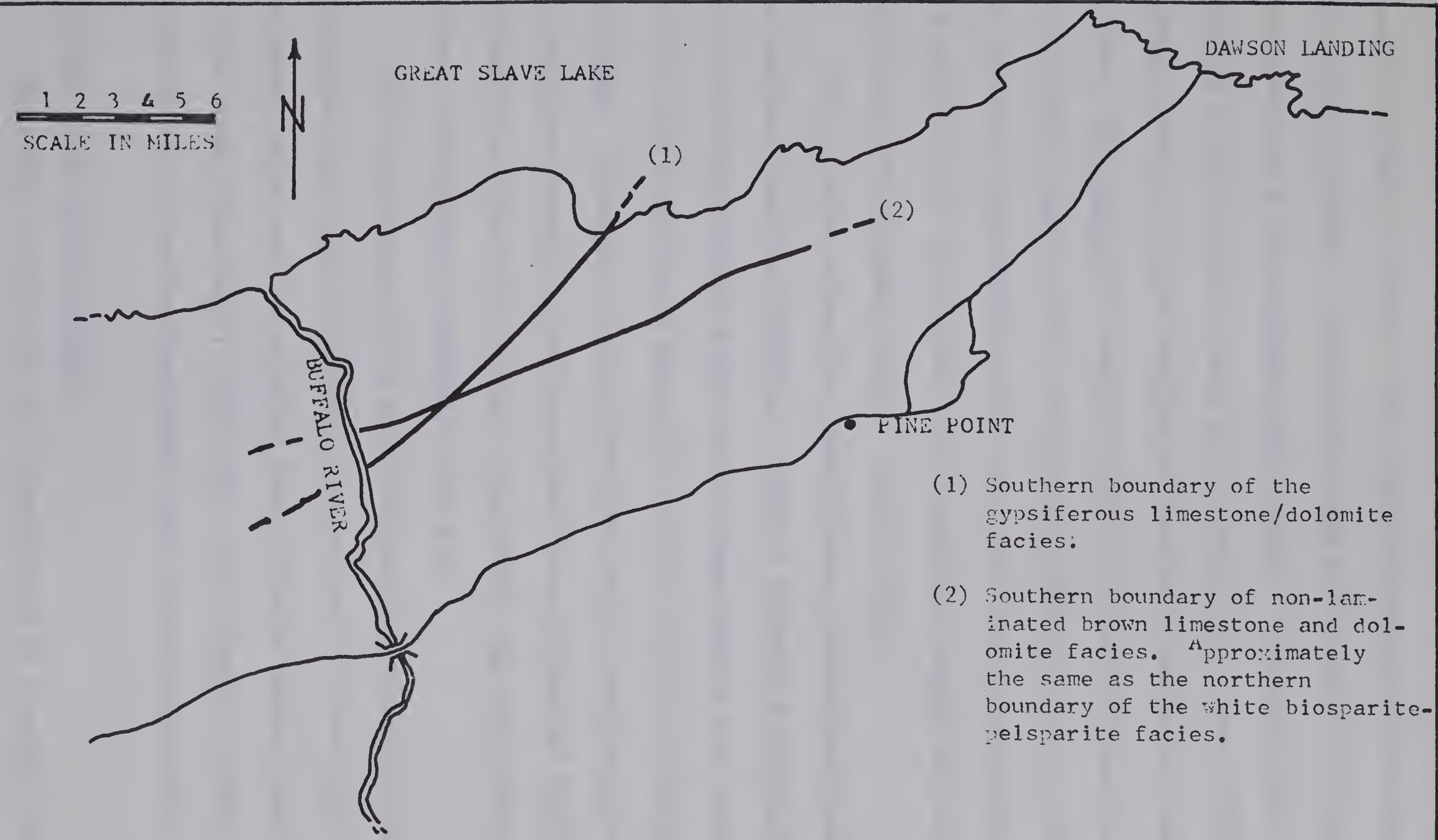


FIGURE 13: PINE POINT AREA. GENERALIZED DISTRIBUTION OF SOME FACIES IN THE SULPHUR POINT FORMATION. SEE FIGURE A18 FOR DETAIL AND CONTROL.

The brachiopods are usually whole, commonly disarticulated, but not usually broken or abraded. They are often abundant in certain beds but are sparse in others. Occasionally they are replaced by pyrite or have cavities filled with sphalerite and galena. The shells often exhibit beekite on the exterior shells (A.W. Norris, pers. comm. 1970). Crinoids usually occur as single ossicles and are not concentrated into discrete layers. Thamnopora are usually lying with their long axes parallel to the bedding (Fig.5:6, 6:6). Grey chert commonly occurs in this facies as scattered replacement nodules one to two inches in diameter. Chert is restricted to this facies of the carbonate complex and very probably developed from original skeletal opaline silica.

The dolomite varies from fossiliferous aphanocrystalline dolomite to medium-crystalline dolomite. Abundant bituminous material gives the unit its characteristic black to dark brown colour; and, where concentrated with argillaceous material, produces irregular bedding and shaly partings. Porosity is usually very low, but an early stage of intercrystalline porosity in medium-crystalline equigranular hypidiotopic dolomite is filled with calcite. Occasional vugs occur within the outlines of dolomitized brachiopods (Fig.5:2).

This facies occurs as a belt intertonguing with the bituminous limestone part of the facies to the north and with the friable brown dolomite facies and the cohesive brown dolomite facies (described later) to the south (Figs.A6, A7, A11, A18). The sediments of this facies are interpreted to have been deposited under low energy subtidal conditions.

Friable Brown Dolomite Facies

The rocks of this unit are characterized by a medium brown colour, fair to good intercrystalline porosity, and usually a very friable

texture. The friable nature has led to the common name "sandy brown dolomite" or "dolomite sand" for this lithology. In thin section it consists of equigranular fine- to medium-crystalline idiotopic dolomite with minor amounts of bitumen lining pores. In broken samples a strong smell of hydrocarbons is often present. Cementation by calcite is common, and gypsum or anhydrite cement occurs rarely. Gypsum cement, nodules, and replacement veinlets are found in this facies in the southwestern part of the study area (Figs.11, A18).

The unit is typically featureless, but two special rock types are recognized. One of these is characterized by laminations, probably of algal origin; the other contains relict outlines of bioclastic debris. They are usually also less friable and have a smaller crystal size, often finely crystalline. These two rock types constitute only a small part of the facies as a whole.

The porous, friable brown dolomite facies is the predominant material of the Pine Point Formation as shown on sections A2-A14. In plan (Fig.A15) it covers the entire study area south of the line designating the southern boundary of the bituminous limestone/dolomite facies. Some of it lies to the north of this line intertonguing with the bituminous limestone/dolomite facies. It also intertongues with the cohesive dolomite facies described later.

A bed (beds) of this facies wedges into the coarsely crystalline dolomite facies from the south forming the C marker. Along the southern side of the study area it occurs as one bed which splits into 2 or 3 beds farther north (Figs.A2-A14) separated by coarsely crystalline dolomite. The northern margin of the marker trends east-northeast parallel to the trend of the coarsely crystalline dolomite facies (Figs.A1, 12).

Any interpretation of the original nature of this unit is open to question, but it appears to have formed from the dolomitization of calcarenites and calcilutites. It undoubtedly contains some lagoonal sediments since it contains abundant Amphipora in the southern part of the study area. It also contains Stringocephalus on one of the Burnt Islands group (A.W. Norris, pers. comm. 1970).

(a) Bioclastic Brown Dolomite Sub-Facies

This rock type has the same basic lithology as the friable brown dolomite facies but is subdivided on the basis of relict bioclastic outlines. Examples of these are shown in Figs.6:5, 6:8. The recognizable whole fossils in the illustrations are atypical. More commonly the outlines of fragments are obscure (and non-photogenic) but still suggest a bioclastic nature of the rock (Fig.3:1).

The distribution of this rock type within the porous friable brown dolomite facies does not appear to follow any particular pattern (Figs. A2-A12). It may be more common along the southern part of the drilled area as it occurs in the southernmost holes on Figs.A6, A7, A11, and A12; but it is not confined to these areas. Recognition of this rock type may depend in part on the presence of Amphipora fragments which are recognizable even after dolomitization.

This rock type was deposited at least partly in shallow water where waves acted on biogenic material reducing it to calcirudites and calcarenites. Some of it was deposited in restricted environments as indicated by the presence of Amphipora.

(b) Laminated Brown Dolomite Sub-Facies

A laminated appearance permits subdivision of this rock type from

the friable brown dolomite facies. It is usually less friable but has vuggy porosity in places. Variations of this rock type are shown in Figs.5:8 and 6:1-6:4. Some of these (Figs.6:1, 6:2) indicate disturbance of bedding by burrowing organisms and either solution or storm action. Specimens shown in Figs.6:3 and 6:4 contain large clusters of milky-white calcite crystals which have laminae bending around them. The calcite commonly has native sulphur associated with it. The clusters were probably formed during sedimentation as gypsum or anhydrite nodules and were replaced later by calcite. This rock type contains only a few Amphipora and lacks other recognizable fossils.

The laminated brown dolomite lies in a belt along the south side of the study area (Figs.11, A18). It is believed to represent deposition in intertidal to supratidal areas with patches of sabkha environment. The laminations are probably due in part to the influence of algal mats. Brecciated layers such as shown in Fig.6:2 may be due to the solution of evaporites or disturbance and redeposition of fine-grained sediments during storms.

Cohesive Brown Dolomite Facies

This unit has a distribution similar to the friable brown dolomite facies and is complexly interbedded with it in places. However, it is much less abundant than the friable brown dolomite facies and usually occurs on top of it and comprises the D3 marker bed. It is characteristically light brown or light bluish-grey, compact, and has minor vuggy, pin point, and fracture porosity. In thin section it consists of finely crystalline to very finely crystalline dolomite with an equigranular hypidiotopic fabric. Bitumen, sulphur, and calcite commonly occur as pore-linings or pore-fillings.

In its uppermost bed the facies has a characteristic brecciated appearance and is designated as the D3 marker bed. The brecciated appearance is commonly due to intensified grey colour along fracture zones; but in other places, brecciation is striking (Fig.3:3) with fragments rotated and surrounded by coarsely crystalline white dolomite. Marcasite, sphalerite, and galena commonly line vugs in this bed.

This facies contains few fossils; but molds of crinoids, Amphipora, and brachiopods have been observed. Outlines of colonial corals and subspherical stromatoporoids occur in the D3 marker bed. The areal distribution of the D3 marker bed is shown on Figs.12 and 18. It wedges out from the south along an east-northeast trending line and occurs only as patches near the Buffalo River. This bed probably originated as a solution breccia during a period of exposure. It is doubtful if a slump breccia of this mass, relatively even distribution, and nearly horizontal nature could have developed with the low relief inferred for the carbonate accumulation during deposition of the D3 bed. The origin of the remainder of the facies is difficult to establish; it may represent dolomitized micrite.

Coelenterate Biolithite and Rubble Facies

Scattered intersections of coelenterates forming biolithite and coarse rubble are grouped into this facies. Massive and platy stromatoporoids, rugose and dendroid corals are the characteristic fossils. Some stromatoporoids have been demonstrated to have the ecologic potential to erect wave-resistant structures, and others are characteristic of fore-reef detritus zones. They are illustrated in Figs.5:3-5:7, 7:1 and 7:2. Some of the occurrences are dolomitized and some are partly replaced by gypsum. Whether this facies represents a reef in the

restricted ecologic sense will be discussed later.

The lowest strata containing this facies are intersected by hole PS66-2 (Fig.A1, 36000E, 42000N) between 585 and 650 feet. Platy dendroid and subspherical stromatoporoids and colonial corals (Fig.5:3) occur in a finely crystalline biogenic dolomite. None of the stromatoporoids appear fragmented, abraded, or rotated from growth position; and some of them have enveloped thin layers of clastic material during growth. Correlation of this material to the north is not possible due to lack of drill holes.

Holes CW310-402 and CW309-502 (Figs.A1 and A2) also intersect this facies. Two rock types occur:

1. abundant Thamnopora, platy and subspherical stromatoporoids in an argillaceous fine- to medium-crystalline dolomite matrix (Fig.5:4)
2. large solitary corals, Thamnopora, Stachyodes?, with stromatoporoid-algal coatings, and brachiopod fragments in a slightly argillaceous biosparite matrix (Fig.5:5)

Coral rubble was intersected in hole 1351 (Fig.A6) as shown in Figs.5:6 and 5:7. Massive stromatoporoids, Thamnopora, and brachiopods (Figs.7:1 and 7:2) occur in hole 1343 (Fig.A12). Scattered stromatoporoids occur in various places in the dolomite facies but are not well enough preserved to indicate whether they are in place or fragmented.

The occurrence of stromatoporoids in place, associated with coral and stromatoporoid rubble suggestive of a fore-reef rubble zone, indicates that this unit accumulated early in the wave zone (possibly the surf zone) and in deeper water on the basinward (north) side of the zone of wave action. Argillaceous and bituminous matter occur in part

of the facies, indicating deposition in deeper water, protected from wave action.

Dark-green Shale Facies

Soft, dark bluish-green, pyritic calcareous shales lie in a belt along the north side of the study area (Figs.11, and A18) and intertongue with carbonate facies to the south (Figs.A2, A6, A10-A12). The shale contains abundant pyrite nodules, disseminated pyrite grains, and discrete laminae up to 1 mm. thick of granular pyrite. The unit usually contains few megafossils, but where it is interbedded with the non-laminated brown limestone and dolomite facies, brachiopods are common. The brachiopods are often whole, frequently disarticulated, but not usually broken. They are sometimes pyritized in the area where the shale intertongues with carbonates (Figs.A11, A12).

This unit is interpreted as a basinal shale deposited below wave base in front of a carbonate accumulation that reached into the zone of wave action. The abundance of pyrite indicates at least a local restriction from aeration near the sediment-water interface, a situation that would generally occur only below wave base.

Coarsely Crystalline Dolomite Facies

This facies forms the Presqu'ile Formation and is characterized by its coarsely crystalline to extremely coarsely crystalline grain size and a buff to bluish-grey colour. It is usually vuggy, and vugs are lined with coarsely crystalline white and grey dolomite commonly called 'vein' dolomite. In pit walls the unit is seen to be evenly bedded, with beds varying from 1-12 feet in thickness. Vuggy to cavernous porosity is controlled by the bedding (Fig.4:1). The lithology is

fairly constant within any particular bed but varies greatly between beds.

Thin section studies reveal little with respect to the nature of this facies prior to dolomitization. The rock consists of very coarsely crystalline to extremely coarsely crystalline hypidiotopic to xenotopic dolomite with some inclusions of carbonaceous material and sulphides, and some bitumen and calcite in vugs. Coarsely crystalline white and grey dolomite lines and fills fractures (Figs.4:5 and 4:6). Rarely, relict bioclastic textures occur within the dolomite crystals.

A wide range of peculiar textures and structures are observed on polished surfaces of cores. Plates 1-4 illustrate these, and in some cases captions indicate their probable origin. Fossils are usually obliterated by dolomitization but amphiporids and brachiopod debris are recognizable as shown on Fig.A16. Scattered and less commonly abundant subspherical stromatoporoids can be seen in some beds exposed in the pit walls. Crude outlines of the fossils remain in the coarsely crystalline dolomite. The internal structure of the fossils is often indicated by the pattern of vug development.

Amphiporids are concentrated in the southern part of the facies (Figs.9, A16). These amphiporids are responsible for some of the textures, e.g. Figs.1:5 and 1:6, and beds up to 12 feet thick in the O42 pit consist entirely of amphiporid remains. Fossil fragments are recognizable in some cases but cannot be identified even at the phylum level e.g. Figs.2:1, 2:2, 2:5. Other features such as those illustrated in Figs.1:1-1:4, 1:7 and 1:8 suggest fossil outlines but are probably of inorganic origin.

Boxwork dolomites occur as beds in several pit walls. This

dolomite, shown in Figs.3:7 and 3:8, consists of a boxwork or cell structure with very high porosity. The thin walls between cells consist of very coarsely crystalline dolomite radiating from a center line (fracture?) toward adjacent cells. The porosity is due to leaching of the material (dolomite, limestone, or possibly sometimes anhydrite) from between fractures.

The coarsely crystalline dolomite underlies much of the study area in a broad east-northeast trending belt as shown on Figs.12 and A18. The eastern margin is irregular due to erosional truncation of a gently folded sequence of strata. The coarsely crystalline dolomite reaches a maximum thickness of about 200 feet along the center of the belt and wedges out to the north (Figs.A2-A14). To the south it thins and is interbedded with the overlying white biosparite -pelsparite facies and the underlying friable brown dolomite facies.

The upper contact of this facies with the white biosparite-pelsparite limestone facies is very irregular, and interbedding of the two facies is common. Isolated lenses of the white biosparite-pelsparite facies are enveloped by the coarsely crystalline dolomite facies in the walls of N42 pit. Green shale from the bright green shale facies occurs between beds of coarsely crystalline dolomite in the O42 pit walls.

The coarsely crystalline dolomite facies probably originated by recrystallization of earlier-formed dolomite, and in part by the dolomitization of limestone. The dolomitization and recrystallization sequence is discussed further in a section on diagenesis.

(a) Laminated Vuggy Dolomite Sub-Facies

Beds with distinctly laminated, and laminated vuggy fabrics occur within the coarsely crystalline dolomite facies. The rock consists of

coarsely crystalline hypidiotopic to xenotopic dolomite with layered vuggy porosity that is commonly lined with coarsely crystalline white and grey dolomite (Figs.4:1 and 4:3). The rock type shown in Fig.4:3 is the most common type assigned to this facies in small-diameter core specimens. The bedded nature of the porosity is not always discernable in cores from beds similar to those shown in Fig.4:1. The distribution of this rock type, in core samples, is limited to three occurrences along the southern margin of the coarsely crystalline dolomite facies (Figs.12 and A18). However, it is a common rock type in pit walls of the N42 and O42 pit walls (Figs.A1). It is believed to have formed by dolomitization of laminated limestone or recrystallization of dolomite as shown in Figs.4:2 and 4:4. Evaporite solution may be responsible for some of the layered vugs, as bedding plane surfaces such as those shown in Fig.4:3 often have reticulate patterns. Similar patterns are observed in rocks where fractured anhydrite and gypsum have dolomite selvages forming along fractures. Leaching of the evaporite leaves vuggy porosity and a breccia-moldic pattern. Preferential leaching of limestone from dolomite could also produce these features.

(b) Latticework Dolomite Sub-Facies

Exposures in pit walls reveal the occurrence of beds and lenses with large box-shaped horizontal vugs as shown in Figs.3:5 and 3:6. The overall fabric resembles a latticework. This rock is vertically fractured with extremely coarsely crystalline dolomite (crystals over 1 cm. long) radiate in both directions from the fractures. Horizontal remnants of brown less coarsely crystalline xenotopic dolomite, are rimmed on both sides by radiating coarsely crystalline dolomite (Fig.5:5). Latticework dolomite beds, up to 5 feet thick, can be traced for a few hundred

feet in pit walls. In places they grade laterally to pseudo-breccia or laminated vuggy dolostones similar to that shown in Fig.4:1. Other lenses of this rock type grade into massive dolomite beds containing abundant Amphipora remnants.

This rock type is recognized in drill core from several localities, as shown on Fig.A18. These occurrences are concentrated in a belt on the southern side of the coarsely crystalline dolomite facies. This rock type would be prone to core grinding and core loss and is thought to be more prevalent than indicated by the number of occurrences shown. Drillers' reports commonly show 'cave' intervals of a few feet, many of which may represent rapid drill advance, with little core recovery, through latticework beds.

This rock type is thought to have originated in part due to fracturing and late-stage dolomitization of interlaminated finely crystalline dolomite and anhydrite such as shown in Figs.8:3 and 8:4. The anhydrite (or gypsum) dissolved to create vugs and the dolomite remained as brown dolomite remnants. Interlaminated limestone and dolomite could produce the same effect but the lenticular nature of the occurrences, and the presence of gypsum/anhydrite in the carbonate rocks of the area, indicates the need to consider the evaporite-solution interpretation as a possibility. The probable sequence of events is presented diagrammatically in Fig.14.

(c) Dolomite with Anhydrite Pseudomorphs Sub-Facies

This rock type is characterized by intimate intergrowths of calcite and dolomite. It occurs near the top of the coarsely crystalline dolomite facies, usually penetrating into the overlying white biosparite-pelsparite facies. In some cases both the calcite and dolomite are very

coarsely crystalline (3-4 cm.) but often both are medium to coarsely crystalline and the calcite is pseudomorphous after anhydrite or celestite crystals (Fig.7:3). Similar pseudomorphs (Fig.7:4) are common in all facies along the southern side of the study area, but do not generally reach the proportion of half of the total rock.

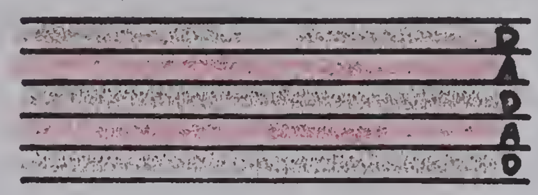
The few occurrences of this rock type do not permit generalizations on its distribution. In D.D.H. 136 (Fig.A11) the rock type is well developed. Immediately to the south, in the laterally equivalent white biosparite-pelsparite facies, pelsparite and pelmicrites contain 10-20 percent of calcite rosettes pseudomorphing original anhydrite. This is taken as evidence that the dolomite with anhydrite pseudomorphs originated due to the original intimate deposition of evaporite and limestone and/or dolomite, followed by late-stage dolomitization.

Summary

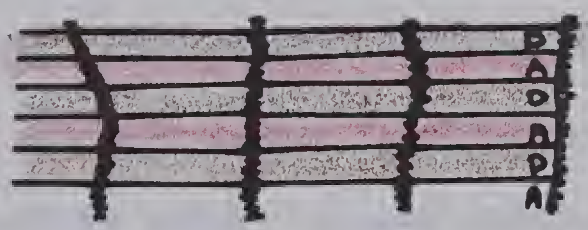
The coarsely crystalline dolomite is thus seen to be in part a sedimentary feature and in part diagenetic in origin. Although the distinctive lithology is laterally equivalent, in part, to the limestones of the Sulphur Point Formation, the dolomite of the Pine Point Formation, and the shale of the Buffalo River Formation, it forms a distinct stratigraphic interval and reflects a particular depositional environment. The unit is interpreted to have been deposited mainly in a shallow-water to supratidal environment with abundant Amphipora, lagoons, sabkhas and algal mud flats, sheltered from the open sea to the north by scattered patches of coelenterate growth. Periods of more open circulation permitted proliferation of subspherical stromatoporoids, Stachyodes, and brachiopods. Wave action washed the skeletal material into widespread beds of uniform thickness.

FIGURE 14: DEVELOPMENT OF LATTICEWORK STRUCTURE IN THE COARSELY CRYSTALLINE DOLOMITE FACIES (SEE ALSO FIGS.3:5, 3:6, 8:4).

STAGE 1: ORIGINAL MATERIAL COMPOSED OF INTERLAMINATED FINE-GRAINED DOLOMITE (D) AND GYPSUM/ANHYDRITE (A).



STAGE 2: FRACTURING AND GROWTH OF DOLOMITE ALONG FRACTURES; RECRYSTALLIZATION OF INTERBEDDED DOLOMITE (?)



STAGE 3: REMOVAL OF GYPSUM/ANHYDRITE AND PRECIPITATION OF WHITE RADIAL DOLOMITE ON REMNANTS OF BEDDED DOLOMITE. SOME COLLAPSE OF INTERBEDDED DOLOMITE. ROCK NOW HAS LATTICEWORK STRUCTURE AND GOOD VUGGY POROSITY (V).

The characteristic coarsely crystalline nature of the facies was probably produced by a later overriding phase of recrystallization of earlier-formed dolomite, dolomitization of limestone and development of coarsely crystalline, vug-lining sparry dolomite. The present boundaries of the facies are defined by this late diagenetic effect.

White Biosparite-Pelsparite Facies

A cream to white, tightly-cemented limestone overlies and intertongues with the coarsely crystalline dolomite facies. The unit is thick-bedded, with stylolitic bedding surfaces a common feature. The white biosparite-pelsparite facies can be subdivided into four rock types when logged in detail. The overall distribution and fossil content is discussed under subheadings. The general relationship of the white biosparite-pelsparite to adjacent facies is shown in Fig.15. In plan, the white biosparite-pelsparite facies is approximately coextensive with the coarsely crystalline dolomite facies (Fig.A16) but it extends southward beyond the study area. The eastern margin is irregular due to erosional truncation.

The distribution of fossils in the entire white biosparite-pelsparite facies and the laterally equivalent part of the dark-green shale facies are plotted on Fig.A17 and generalized on Fig.10. In general, horn corals, Thamnopora and thin-shelled brachiopods occur toward the north but the rest of the fossils including Amphipora, Stachyodes, subspherical and tabular stromatoporoids, gastropods, horn corals, Stringocephalus and thick-shelled brachiopod debris (partly Stringocephalus)* appear to be scattered throughout the facies.

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* Probably many are Warrenella because this genus is far more abundant (in outcrop) in the Pine Point area (A.W. Norris, pers comm. 1970).

(a) Whole-fossil Biosparite-pelsparite Sub-facies

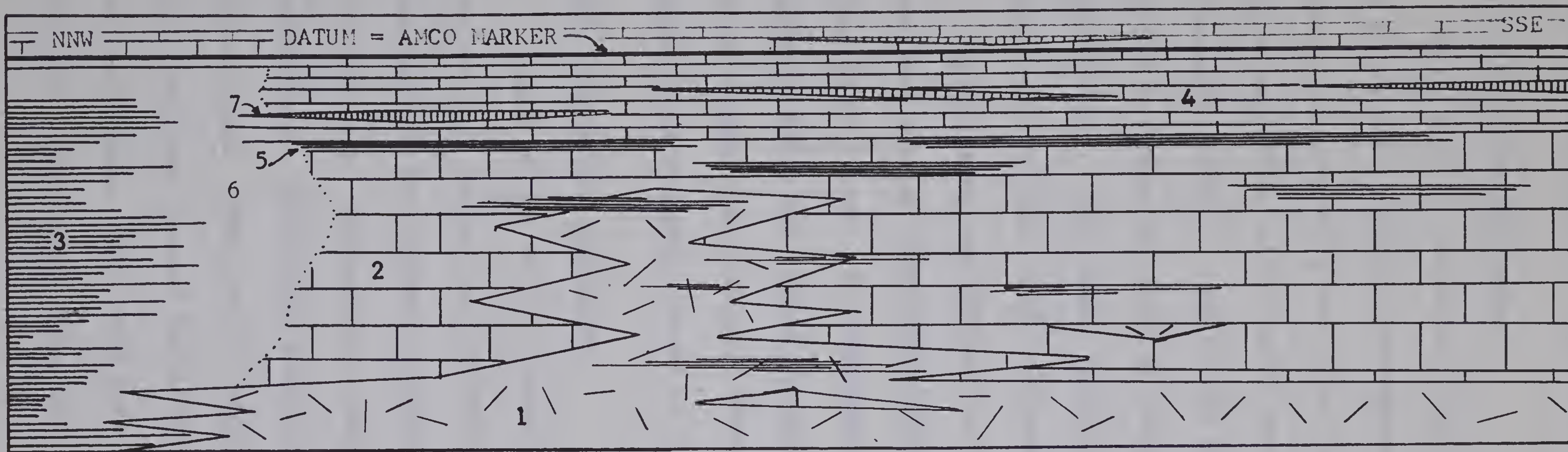
This rock type consists of tightly cemented white limestone with whole fossils in growth position or little transported from their growth site. One of the most common whole fossils is the thick-shelled brachiopod Stringocephalus which is found in biosparites and biosparrudites e.g. Fig.7:5. Another rock type is a subspherical stromatoporoid-coral-Amphipora biopelmicrite or pelmicrite e.g. Fig.7:7. Lenses of these rock types, enveloped by the coarsely crystalline dolomite facies, are found in the walls of N42 pit. The lenses contain scattered tabular stromatoporoids four inches thick and three feet wide, and subspherical stromatoporoids up to one foot in diameter, in growth position, in a biopelsparite matrix. Similar stromatoporoids occur in a biosparrudite matrix in a similar setting in the J44 pit.

The distribution of this rock type appears to be random within the white biosparite-pelsparite facies. It represents accumulation in both turbulent water (to form calcarenites) and in quieter lagoonal water (to form Amphipora pelmicrites).

(b) Biosparrudite Sub-Facies

Biosparrudites and coarse biosparites (Figs.7:6 and 7:8) are common rock types in the white biosparite-pelsparite facies. They vary from well-sorted and mature to poorly sorted and immature, but all are tightly cemented with sparry calcite and commonly have bitumen along former porous zones. Fossil fragments are recognizable as gastropods, brachiopods, Stachyodes, Amphipora, and platy and subspherical stromatoporoid fragments. Some of the stromatoporoid fragments have oncolitic coatings.

The distribution of this rock type also appears to be random. However, Figs.A4 and A12 show it to lie to the north of the pelsparite rock



LEGEND

7 GYPSIFEROUS LIMESTONE/DOLOMITE FACIES
6 NON-LAMINATED LIMESTONE AND DOLOMITE FACIES
5 BRIGHT-GREEN SHALE FACIES
4 LAMINATED BROWN LIMESTONE AND MOTTLED DOLOMITE FACIES
3 DARK-GREEN SHALE FACIES
2 WHITE BIOSPARITE-PELSPARITE FACIES
1 COARSELY CRYSTALLINE DOLOMITE FACIES

NOT TO SCALE. THE ABOVE AREA REPRESENTS 200 FEET VERTICAL BY ABOUT 8 MILES HORIZONTAL

FIGURE 15: DETAILED RELATIONSHIP OF LITHOFACIES COMPRISING THE SULPHUR POINT FORMATION AND ADJACENT UNITS. FACIES 4 and 7 ARE IN FORT VERMILION FORMATION.

type and may indicate an increase in grain size toward the north.

(c) Biosparite Sub-Facies

This unit is composed of tight biosparites and some biopelsparites. The rocks were commonly impregnated by bitumen (Fig.8:1) while still porous. The porosity was later tightly filled by mosaic calcite. The grains vary from well-rounded and well-sorted, to poorly rounded and moderately sorted. Some of the fragments have micrite envelopes preserving the outlines but many of the particle outlines are obscured by recrystallization. The cement consists of a drusy calcite rim followed by mosaic calcite that fills all pores.

No patterns are obvious in the distribution of this rock type. It sometimes grades vertically into the biosparrudites but lateral correlations are tenuous. It originated from the comminution of skeletal material which was washed by waves and deposited in more sheltered lagoonal or deeper water areas. Some of the well-rounded, well-sorted biosparrudites probably formed as beach sediments.

(d) Pelsparite Sub-Facies

Rocks of the white biosparite-pelsparite facies containing abundant pellets and lacking macrofossils other than Amphipora were grouped as pelsparites for regional analysis (Figs.A2-A14). Common rock types included are: pelsparite, pelmicrite, Amphipora micrite, and Amphipora pelmicrite. Occasional gastropods and abundant calcispheres occur in these rocks. They are all tight but an original low porosity in some of them has been invaded by bitumen. Fine laminations are often emphasized by stylolites. This rock type is typically very uniform as shown in Fig.8:5. Amphipora, lying with their long axis parallel to bedding, are

sparse to abundant. Rosettes of calcite pseudomorphous after gypsum, anhydrite, or celestite (Fig.8:2) occur in the southern part of the study area. Laminoid fenestral fabrics (Tebbutt, Conley and Boyd, 1965) occur (Fig.9:2). Occurrences of this rock type are abundant toward the southern side of the study area but are also found throughout the white biosparite-pelsparite facies. This subfacies probably originated in quiet water lagoons where organisms pelleted the muddy sediments. Some exposure in the supratidal zone is indicated by the laminoid fenestral fabric, and restriction of water is indicated by the occurrence of the presumed anhydrite or celestite pseudomorphs, Amphipora, and calcispheres.

Bright-green Shale Facies

A number of waxy 'apple-green' shale beds and lenses occur in the upper part of the white biosparite-pelsparite facies. As already noted, the shales and the interbedded limestones can be considered the correlative of the Watt Mountain Formation. These shales are considered to constitute a separate facies, and the interbedded limestones are grouped with the white biosparite-pelsparite facies. The shales have both gradational and sharp contacts with the limestones. The upper shale beds commonly contain Charophytes. Disseminated fine-grained marcasite is widespread.

Limestone rubble is often found within the shale, and shale inclusions and seams in limestone beds are common. In pit walls the green shale occurs as lenses between coarsely crystalline dolomite beds (dolomitized white biosparite-pelsparite facies). The shale beds vary in thickness, as the shale fills pockets and irregularities on the underlying bedding or erosional surfaces. The shale also fills vertical fissures up to 1 foot wide that transect dolomite and limestone beds for several feet in

pit walls and extend to the present erosional surface. Shale lenses extend for a few hundred feet laterally and vary from two feet thick down to thin shaly partings between dolomite beds.

In the vicinity of the Buffalo River, some gypsum is mixed with shale beds of this facies (Fig.A6, D.D.H. 1380, 1382).

The bright-green shales are thought to represent periods of shallow water and temporary breaks in carbonate accumulation. The irregular bedding planes and rubble occurrences may be in part due to surface weathering. The presence of Charophytes indicates that pools of fresh to brackish water persisted in the area at times during deposition of the shale, (Peck and Morales, 1966, p.303). The fresh water pools may have existed in some areas while salinas elsewhere on the carbonate accumulation precipitated a mixture of gypsum and shale. The source for the argillaceous material was probably the Peach River Arch to the southwest since the clastics of the Watt Mountain Formation elsewhere are thought to have been derived from that source (Kramers and Lerbekmo, 1967). Some of the argillaceous material may have come from the north but it is not usually calcareous as are the shales of the Buffalo River Formation.

Gypsiferous Limestone/Dolomite Facies

This facies contains abundant gypsum and anhydrite mixed with dolomite, some limestone, and shale. The facies occurs in an area where groundwater circulates into the strata at present, so the gypsum may have formed by the recent hydration of anhydrite, rather than as an original sediment that has persisted through time.

Typical lithologies are illustrated in Figs.8:3 and 8:4. One consists of finely interlaminated light-brown finely crystalline to aphanocrystalline dolomite and clear to light brown, fine- to medium-

crystalline anhydrite. The other type is composed of irregular nodules and bands of anhydrite. Both types are visible in Fig.8:4 and they commonly are interbedded.

Fibrous and felted masses of gypsum occur with both the green shale facies and the white biosparite-pelsparite facies in D.D.H. 1380 and 1382 (Fig.A6) and D.D.H. 1383 (Fig.A7). In this area the facies occurs as a lens within the white biosparite-pelsparite facies. Some sections of gypsiferous white limestone intersected near the top of the Cominco G-4 well would also be placed in this facies. The interlaminated dolomites and anhydrites occur as lenses, up to 30 feet thick and one half mile wide, within the laminated brown limestone and mottled dolomite facies and also within the mottled dolomite facies. The facies is best developed in D.D.H. 1350 (Fig.A6) and D.D.H. 1384 (Fig.A7) in the northwestern part of the study area outlined on Fig.A17. Vuggy porosity is common in the laterally equivalent strata, thus it is possible that evaporites were previously more widespread and were removed in some areas by surface leaching, while remnants are preserved where the zone is more deeply buried.

The laminated and nodular dolomite and anhydrite is interpreted to be a sabkha-type deposit. The nodular anhydrite probably formed as nodules within the sediment below the sediment-water interface. The interlaminated dolomite and anhydrite probably represent flooding of the sabkha with direct precipitation of anhydrite and dolomite at the sediment-water contact. The gypsiferous bright green shale and white biosparite-pelsparite facies probably represent deposition in isolated pools and salinas on the surface of a widespread lagoonal limestone accumulation.

Non-laminated Brown Limestone and Dolomite Facies

This facies is established partly on the basis of lithology and partly on stratigraphic position. It is characterized by medium-crystalline dark brown dolomites, and medium- to dark-brown biosparites, biomicrites and micrites which are argillaceous, bituminous and fossiliferous. An overall feature is that they lack the well-developed regular laminations that are developed in similar laterally-equivalent lithologies. They have some wispy irregular laminations and argillaceous partings. A specimen from this facies, better-laminated than usual, is shown in Fig. 6:6. Thamnopora, horn corals, thin-shelled brachiopods, crinoid ossicles and subspherical stromatoporoids occur parallel to the bedding in this facies and are not abraded or badly broken. Similar material is illustrated in Figs.2:2-2:4, 5:1 and 5:6, 7:1 and 7:2.

Rocks of this facies are usually tight except where fossils have been replaced by anhydrite which has been partly removed by leaching to create vuggy porosity. Some porosity also occurs in the medium-crystalline hypidiotopic dolomites.

The non-laminated brown limestone and dolomite facies intergongues with the dark-green shale facies to the north as shown in Fig.A-12. In a lateral distance of 4,000 feet from R.H. 34 to D.D.H. 1343 the section changes from predominantly non-laminated brown limestone and dolomite facies to predominantly dark-green shale facies. It is laterally equivalent to the laminated brown limestone and mottled dolomite facies, the white biosparite-pelsparite facies and the coarsely crystalline dolomite facies to the south (Fig.A6).

Laminated Brown Limestone and Mottled Dolomite Facies

This facies is composed of a number of rock types, all characterized

by well-developed laminations, vuggy porosity, or mottles which lie roughly parallel to the bedding. The limestones and dolomites generally resemble the specimens shown in Figs.4:2 and 4:4 respectively. Both limestones and dolomites are characteristically unfossiliferous to sparsely fossiliferous. The banding may be due to algal mats. Burrowing organisms probably caused some of the mottling in the dolomite, but other forms of life are not in evidence.

The limestones are composed of micrite, pellets, fine unrecognizable bioclastic particles, and some sparry cement. Isolated dolomite rhombs are abundant and patches of the rock are composed largely of dolomite rhombs. Vuggy porosity that parallels bedding is partly lined with bitumen and calcite. Vugs are often rectangular, suggesting solution of evaporitic minerals. Disturbed bedding and crenulations may be due to either dessication cracks or crumpling of algal mats during deposition.

Beds of mottled dolomite are interbedded with the laminated limestones. They are tan to grey, with dark-grey, irregular, mottled patches caused by finely disseminated pyrite and bitumen. The rock is usually a tight, aphanocrystalline to finely crystalline, hypidiotopic to xenotopic dolomite. This facies overlies the white biosparite-pelsparite facies and is laterally equivalent to the non-laminated brown limestone as shown on Figs.A2-A12. It is interpreted to have formed in a supratidal to intertidal environment.

Argillaceous Dolomitic Limestone Facies (AMCO)

Limestone and dolomitic limestone with a high content of argillaceous material compose this facies. The rock usually has a good shaly parting. Scattered pyrite is abundant and clusters of pyrrhotite crystals are common. Whole and disarticulated brachiopods and crinoid ossicles occur

in one-foot layers at the top and bottom of the facies (Fig.9:1). Crinoid ossicles are sometimes scattered throughout. Mottling and worm burrows are observed in some samples. However, unless the core is slabbed, these features are not visible and are missed during field logging.

Thin section examination reveals that the finely crystalline euhedral dolomite rhombs can be either scattered uniformly throughout an argillaceous micritic matrix or may be concentrated along certain laminae and burrows. Brachiopod shells have usually retained their fibrous calcite structure.

This facies makes up one bed in the study area--the Amco marker bed. It overlies the laminated brown limestone and mottled dolomite facies but is considered to be part of the well-bedded brown fine-grained limestone facies. Another two-foot bed of the same type immediately overlies the argillaceous carbonate facies. On Fig.A6 it appears that the argillaceous carbonate may be a tongue of the dark-green shale facies.

This facies originated in a fairly deep quiet water environment with little wave action. The fossiliferous bands at the top and bottom indicate shallower water at the start and end of deposition of the facies.

Mottled Dolomite Facies

Grey and tan dolomites, mottled with grey, such as shown in Fig.4:4, commonly occur in the basal part of the bedded, brown, fine-grained limestone facies. They are typically tight, finely crystalline, with a hypidiotopic to xenotopic fabric. No fossils occur in this facies but mottles suggest activity of burrowing organisms.

This facies occurs throughout the western part of the study area but is eroded to the east. It contains essentially the same dolomite types as the laminated brown limestone and mottled dolomite facies, and is

believed to have formed in a supratidal to intertidal environment similar to that proposed for the latter facies.

Bedded Brown Fine-grained Limestone Facies

A variety of limestone types are grouped into this facies. All of them are characterized by a medium-brown colour, presence of bituminous material, very low porosity, and well-developed bedding. Beds are usually from 6 inches to 3 feet thick.

Beds of subspherical stromatoporoids up to 5 inches in diameter (Fig.8:7), but averaging 2-3 inches, occur throughout the facies. The stromatoporoids are usually rotated from growth position and have a biosparite matrix between them.

Finely laminated carbonaceous micrite beds (Fig.8:8) are common. Laminations are often irregular and indicate minor channel-filling. Beds of biosparite and biomicrite make up most of the remainder of this facies. A few zones up to 20 feet thick of intramicrite and intrasparite occur near the top of this facies in the vicinity of the Buffalo River. Farther to the west some of the intraclasts have oncolitic coatings (Fig.8:6).

Some beds of well-laminated vuggy limestones, similar to those of the laminated brown limestone and mottled dolomite facies occur in the basal 20-30 feet of this facies. They are not differentiated on the cross sections because of the less detailed approach taken to strata above the argillaceous dolomitic limestone facies.

This facies normally has abundant small brachiopods, ostracods and some Amphipora throughout except in the finely laminated beds which are unfossiliferous, and in the subspherical stromatoporoid beds which have only one fossil type. The bedded brown fine-grained limestone extends westward over the study area from its erosional edge and is of fairly

uniform lithology throughout. In keeping with its being a grouping of rather varied types, it is interpreted to include shelf limestones deposited in 'normal' marine water with some periods of restriction and occasional exposure to form supratidal dolomites, intertidal to supratidal laminated limestones, oncolites, and beds of intraclasts.

PALEOECOLOGY AND FACIES ANALYSIS INTERPRETATION

The carbonate complex in the Pine Point area is interpreted to be partly a reef complex but the major part of the carbonate rock accumulation is a bank complex with associated abundant supratidal sediments. The whole complex acted as a barrier, separating a restricted basin to the south from an open marine basin to the north. The carbonate rocks accumulated in a hot arid climate, giving rise to reefs and banks with an evaporite association.

Organisms with the ecologic potential to build reefs occur within the complex. Subspherical and tabular stromatoporoids are the most likely builders of a wave-resistant barrier. However, Amphipora, Thamnopora, and brachiopods contributed much of the skeletal material. While the coelenterate biolithite and rubble facies (composed partly of 'reef-derived' rubble) occurs only in limited amounts within the carbonate complex, it is apparent that the carbonate accumulation did attain some relief relative to the adjacent basinal sediments on the north and at times reached into the surf zone. Parts of the carbonate complex in the southern part of the study area accumulated in the supratidal and intertidal zones contemporaneous with sedimentation of quiet water argillaceous sediments to the north. The relief may have been considerable during accumulation of the bituminous limestone/dolomite facies to the north of the friable brown dolomite facies, as intertonguing of the units is not pronounced. The apparent lack of intertonguing may be due to poor core control at this stratigraphic level. However, at a slightly higher stratigraphic level the dark-green shale facies intertongues with the non-laminated brown limestone and dolomite facies to the south, indicating contemporaneous deposition of the two facies without much relief on the

carbonate accumulation.

Regardless of the amount of relief on the carbonate accumulation, the carbonate facies form linear belts with an east-northeast trend (Figs. 11-13 and A15-A17). Evaporitic sediments lie in the southern part of the belt and shaly open-marine sediments lie to the north. This indicates that the carbonate complex was effective as a basin-restricting barrier, and as such can be termed a barrier carbonate complex. However, as some workers regard the term barrier to be inherently associated with reef development, the word barrier might better be omitted in detailed considerations of the carbonate complex. The term 'Presqu'ile barrier' can be used without confusion when referring to the complex in a regional context.

Tyrrell (1969) presented a series of interpreted environments across the Capitan barrier reef complex of West Texas and New Mexico. Most of them can be recognized or inferred in the lower carbonates (below the Slave Point Formation) of the study area. The environments (Tyrrell, 1969, p.80) with analagous facies from the study area are as follows:

1. Evaporite	Gypsiferous facies
2. Mixed carbonate environments	Laminated brown dolomite sub-facies
3. Unwinnowed shelf carbonate	Friable brown dolomite facies
4. Winnowed shelf carbonate	
5. Shelf edge carbonate	Coelenterate biolithite and rubble facies
6. Basin slope	Bituminous limestone/dolomite facies
7. Basin margin	
8. Basinal	
9. "Starved" basin	(not represented)

The coarsely crystalline dolomite facies, the white biosparite-pelsparite facies and their laterally equivalent non-laminated brown

limestone and dolomite facies and dark-green shale facies appear to have developed with limited relief on sedimentation. The coelenterate biolithite and rubble facies occurs in only limited amounts but Thamnopora are abundant in the zone where carbonates and shale intertongue. Sedimentation in this interval may have occurred in a transgressive shallow marine to supratidal environment like that postulated by Shaw (1964, p.430) and Irwin (1965) and demonstrated by Laporte (1969) for sedimentation within an epeiric sea. However, the sequence of facies belts is relatively narrow in the study area (12-15 miles versus 85 miles found by Laporte, 1969) suggesting that this model does not fit the coarsely crystalline dolomite and laterally equivalent facies.

It is interpreted that the mixed carbonate environmental belt postulated by Tyrrell (1969, p.89) greatly expanded in width at the expense of adjacent belts, and covered much of the study area during deposition of the Presqu'ile and Sulphur Point Formations. The expansion was probably due to a lower rate of subsidence of the area, enabling carbonate accumulation to reach sea level with consequent development of beach ridges, supratidal shoals, lagoons, sabkhas, and salinas. The organic reef developed only in patches but storm-beach ridges of Amphipora, Stachyodes, and brachiopod shells helped to form the bank margin. Wave distribution of sediments resulted in the evenly bedded nature of the coarsely crystalline dolomite facies in the study area. Thickly bedded to massive dolomite occurs in the Presqu'ile on the north shore of Great Slave Lake.

The more widespread units: the upper part of the white biosparite-pelsparite facies, the laminated brown limestone and mottled dolomite facies, and the bedded brown fine-grained limestone facies, probably

formed in sedimentary frameworks such as those postulated by Shaw (1964, p.43) Irwin (1965) and Laporte (1969). That is to say, they formed in a widespread epeiric sea with a very low bottom slope that would effectively restrict circulation of water, causing development of saline conditions beyond tidal exchange. A facies mosaic of lagoonal limestones, evaporites, algal-laminated limestones, synsedimentary dolomites, and widespread layers of open-marine subspherical stromatoporoids such as that found in the above-mentioned facies could have developed in a very similar manner to the Helderberg facies described by Laporte (1969).

CHAPTER 4: DIAGENESIS

GENERAL

Post depositional changes in this suite of rocks cannot be subdivided into the stages of syndiagenesis and epidiagenesis along the lines of Fairbridge (1966) since the rocks were probably subjected to several periods of leaching and alteration during and after consolidation. In addition, the rocks have been subjected to a late-stage dolomitization which would be considered by some workers to be a metamorphic effect. However, since no sharp line can be drawn at the onset of metamorphism, the simplest case is preferred i.e. treatment of the rocks as if all postdepositional features resulted from complex diagenetic changes. Thus, the term diagenesis here is used in the broad sense of Murray and Pray (1965) who stated:

> "In its broadest sense diagenesis encompasses those natural changes which occur in sediments or sedimentary rocks between the time of initial deposition and the time--if ever--when the changes created by elevated temperature, or pressure, or by other conditions can be considered to have crossed the threshold into the realm of metamorphism."

In their introduction to the 1965 Symposium on Dolomitization and Limestone Diagenesis, Murray and Pray stated that:

> "Sound geological interpretation of the diagenesis of carbonate rocks is dependent upon our knowledge of four major factors. These are the rocks themselves--the end product; the physical and chemical processes involved; the nature of the intrastratal waters and their movement; the starting materials--the sediments."

The rocks themselves involved in this study, as in most carbonate investigations, present the investigator with a confusing array of features that lend themselves to different interpretations. The nature of the original materials in some of the rocks under investigation can be

determined with a high degree of certainty but much of the carbonate complex is of unknown or inferred origin. However, the particular attention focussed on the associated orebodies has resulted in research that gives us some idea of the chemical and physical processes involved, and the nature of the intrastratal fluids during diagenesis. Sulphur, carbon, and oxygen isotope studies and fluid inclusion investigations throw some light on two of the above points i.e. the nature of the fluids and the processes involved.

Detailed tracing of diagenetic events is not possible for each rock type, but by following the sequence of changes from severely recrystallized dolomite through to relatively unchanged limestone, inferences can be made as to the changes that have occurred in most of the sequence. The treatment of diagenetic effects and processes is necessarily of a reconnaissance nature only, because of the complex dolomitization and later changes that have occurred within this suite of rocks.

CHEMICAL DIAGENESIS

CARBONATE DIAGENESIS EXCLUSIVE OF DOLOMITIZATION

Cementation

The white biosparite-pelsparite facies and parts of the bedded brown fine-grained limestone facies are typically tightly cemented by sparry calcite, and, in places, by dark solid bitumen. The calcite usually forms a microscopic drusy rim on particles and is followed by mosaic calcite and bitumen that fill the remaining pore space. Both drusy and mosaic sparry calcite are also observed to post-date bitumen in pores in some parts of the rock. The calcite cement may have originated from pressure solution along stylolites, as they commonly occur in the white biosparite-pelsparite facies. Another possible origin is by recrystallization of

some particles of the rock with solution transfer and precipitation of calcite as cement. The calcite that post-dates bitumen may have formed by the precipitation of calcium produced by the reduction of sulphate in pore-fluids in the presence of hydrocarbons. This process is discussed in the section on native sulphur.

Occasionally a milky-white sparry calcite rim of encrusting crystals up to 1 mm. long envelopes particles and lines pore-spaces in biosparrudites (Fig.7:8) that are further cemented by clear sparry calcite. The white calcite may have originated as a fibrous calcite rim during early exposure to weathering, similar to subaerially-formed drusy calcite illustrated by Dunham (1969, p.167).

Neomorphism

The term neomorphism was coined by Folk (1965, p.20) for diagenetic processes in limestones in which changes in gross composition do not take place. Neomorphism may be aggradational or degradational in character. The degradation of particle size has been termed "grain-diminution" by Orme and Brown (1963). Grain-diminution of algal colonies to micrite has been observed by Wolf (1965a,b, p.420) and Leavitt (1968, p.329). Bathurst (1966) described the formation of micrite envelopes on molluscan shells due to the influence of boring algae.

Grain-diminution has been observed in biosparites, biopelsparites, and biosparrudites of the white biosparite-pelsparite facies. Micrite envelopes outline fossil fragments which are recrystallized to mosaic calcite. Chalky micrite layers up to 2 mm. thick of probable algal origin, occur on small subspherical stromatoporoids.

Recrystallization of fossil fragments is a common feature in the white biosparite-pelsparite facies and to lesser extent in the bedded

brown fine-grained limestone facies. The outlines of fragments are usually preserved. However, in many places a later phase of patchy recrystallization occurred that obscured grain boundaries. This patchy recrystallization may have been caused by the effects of recent groundwater, but the cause of earlier recrystallization cannot be determined.

<u>Sulphate Replacement of Carbonate; Carbonate Replacement of Sulphate</u>

Some of the porosity in both limestones and dolomites of the study area has developed due to the leaching of gypsum or anhydrite. The sulphate occurs as replacements of both the fossils and matrix of rocks. Figure 5:4 shows an example of stromatoporoids partly replaced by sulphate which was partly removed and the ensuing space was partly occluded by dolomite, creating vuggy porosity. <u>Amphipora</u> pseudomorphed by sulphate occur in the porous, friable brown dolomite facies and the cohesive brown dolomite facies along the southern side of the study area. Immediately to the north of this belt the <u>Amphipora</u> occur as molds, suggesting that they may have been replaced by anhydrite and subsequently leached. Much of the intra-fossil vuggy porosity throughout the carbonate complex is interpreted to have formed by leaching of skeletal material. Some of the fossil material may have been replaced earlier by sulphate.

Calcite clusters commonly occur in the laminated brown dolomite and the brown dolomite facies (Figs.6:3 and 6:2). The calcite often has native sulphur mixed with it. It is believed that the clusters of calcite are pseudomorphs of original anhydrite or gypsum nodules. They may have formed by solution of the sulphate, followed by precipitation of calcite, or by reduction of sulphate to sulphide with the calcium precipitating again as calcite. Calcite commonly pseudomorphs gypsum, anhydrite or celestite crystals (Figs.4:6, 7:3, 7:4, and 8:2).

DOLOMITIZATION

General

Three distinct types of dolomite rocks occur in the Pine Point area:

1. Bedded, compact, mottled, fine- to medium-crystalline dolomites.
2. Brown, fine- to medium-crystalline sucrosic dolomites.
3. Very coarsely crystalline buff-coloured vuggy dolomites.

In addition, dolomite rhombs and patches of dolomite are widespread in the various limestone facies. Aphanocrystalline dolomite occurs interlaminated with anhydrite in the gypsiferous limestone/dolomite facies.

Type 1 dolomites have oxygen isotopes and chemical characteristics distinctly different from the sucrosic and coarsely crystalline dolomites. These differences are displayed diagrammatically and discussed briefly in Appendix F. In general the bedded dolomites are distinguished by their higher $CaCO_3$ content and less negative O^{18} values. Fritz (1969, p.734) favoured the interpretation that this change indicated a lower O^{18} content of the Devonian sea.

The dolomites are of at least two different ages. The scattered dolomite rhombs in limestones, the interlaminated dolomite and anhydrite, and the mottled dolomites (type 1) are most probably of synsedimentary or early diagenetic origin. It is interpreted that the sucrosic dolomites (type 2 above) are also early. The very coarsely crystalline dolomites (type 3) are definitely late (at least later than consolidation of the overlying strata).

The origin of the various dolomite types can be inferred with only varying degrees of certainty, according to the complexities of post-depositional alteration that they have undergone. There are basically three levels of certainty of interpretations:

(a) The compact, mottled, fine- to medium-crystalline dolomites (Fig. 4:4), the isolated dolomite rhombs in laminated limestones (Fig.4:2), and the interlaminated and nodular anhydrite and aphanocrystalline dolomite (Figs.8:3 and 8:4) are all found together in the interval from the bright green (Watt Mountain) shale facies to approximately 50 feet above the base of the bedded fine-grained brown limestone facies (basal Slave Point Formation). They are interpreted to have formed in shallow water to supratidal areas similar to recent dolomites documented on Andros Island, Bahamas (Shinn, Ginsburg, and Lloyd, 1965); on the Trucial Coast of the Persian Gulf (Illing, Wells, and Taylor, 1965); and on Bonaire in the Netherlands Antilles (Deffeys, Lucia, and Weyl, 1965). A strong case can be made for using these areas as modern analogs of the interpreted environments as will be discussed later.

(b) A slightly more obscure case is found in the laminated dolomites with calcite pseudomorphous after anhydrite nodules (Figs.6:3 and 6:4) that are found in the laminated brown dolomite and the friable brown dolomite facies. They are interpreted to be of a similar origin to the dolomite types mentioned in (a) but the rocks have since been more altered.

(c) The laminated vuggy dolomite (Fig.4:3), the latticework dolomite (Figs.3:5 and 3:6), and the dolomite with anhydrite pseudomorphs (Fig.7:3) are all interpreted to have been deposited under conditions analagous to those mentioned in (a). The analogy to modern environments has been complicated and somewhat obscured by the alteration of the rocks in this case to very coarsely crystalline dolomite.

Synsedimentary Dolomites

In the modern analogs of the environments interpreted for deposition

of the dolomites of the study area, studies have shown that dolomite forms due to the concentration of normal marine waters by evaporation. The Mg/Ca ratio is increased by the precipitation of gypsum and/or anhydrite or carbonate cement with the result that the residual Mg-rich brines convert calcitic and aragonitic sediments to dolomite (Deffeyes, Lucia, and Weyl, 1965, p.123; Murray, 1969). In the supratidal flats of Andros Island, the interstitial brines are assumed to become concentrated in a manner similar to those in sediments of Sugarloaf Key in the Florida Keys. The molar ratios of Mg to Ca in the latter area are in excess of 40 to 1 and salinities are 5 to 6 times that of normal sea water (Deffeys, Lucia, and Weyl, 1965, p.123). No evaporites are preserved, but dolomite is formed. This type of environment probably formed the dense mottled dolomites and the limestones containing isolated dolomite rhombs of group (a) above.

In the sabkha environment of the Persian Gulf evaporites (both gypsum and anhydrite) are developing and are preserved in association with penecontemporary dolomite (Illing, Wells, and Taylor, 1965, p.89). In the algal flats associated with sabkhas, laminated sediments are produced which are dolomitized when buried under subsequent sabkhas. The sabkha environment could produce both nodular gypsum/anhydrite with aphanocrystalline dolomite and nodular gypsum in laminated algal sediments, by growth of sulphate nodules below the sedimentary interface (Shearman, 1966, p.209; Illing, Wells, and Taylor, 1965, p.95; Kinsman, 1969, p.830). Periodic flooding could produce laminated anhydrite/gypsum and dolomite. Transgression of the sabkha over the marginal algal-bound sediments would produce both mottled dolomites and dolomite rhombs in limestones.

Brown, Fine- to Medium-Crystalline Dolomites

In the supratidal areas of Bonaire, Netherlands Antilles, gypsum is

precipitating and dolomite is forming by replacement of calcium carbonate due to refluxing of magnesium-enriched brines through the supratidal sediments (Deffeys, Lucia, and Weyl, 1965, p.87; Murray, 1969). If this process were to act on a carbonate sequence for sufficiently long periods the entire calcium carbonate accumulation could be extensively dolomitized.

Dolomitization by the refluxing of brines has previously been proposed by Newell and others (1953, p.179) and by Adams and Rhodes (1960). The widespread brown fine- to medium-crystalline dolomite of the Pine Point Formation and the C marker in the Presqu'ile Formation may well have formed by the prolonged refluxing of magnesium-enriched brines through the carbonate complex during sedimentation.

Other mechanisms for dolomitization proposed for carbonates elsewhere may have been operative on the Pine Point carbonates to form the fine- to medium-crystalline brown dolomites. Goodell and Garman (1969) proposed a model involving "solution-cannibalization" of mixed carbonate phases at sea level to furnish the magnesium for dolomitization in the Superior Deep Test Well, Andros Island, Bahamas. Dolomitization by the channelling of connate water through reefs on compaction of surrounding sediments has been proposed by Illing (1959) for the Leduc reefs of Alberta and by Jodry (1969) for the Silurian reefs in Michigan.

Dolomitization caused by reflux, solution-cannibalization, and channelling of connate fluids could not be distinguished petrographically. Any one, or all three of these processes may have acted to produce the brown, fine- to medium-crystalline dolomites of the Pine Point area.

Precipitation of dolomite in supratidal areas and the dolomitization of the carbonates by the reflux mechanism are favoured for the dolomites of the fine- to medium-crystalline type. The setting, with widespread

supratidal and evaporite precipitating areas, is favourable for these processes.

Very Coarsely Crystalline Dolomite

Very coarsely crystalline, buff and grey dolomites with vuggy porosity are a striking feature of the carbonate complex in the Pine Point area. The distribution of this dolomite in cross section is shown on Figs.A2-A14, and the areal distribution on Fig.A16. This dolomite has a great number of textures and fabrics as illustrated in Plates 1-4.

The most noticeable feature of this dolomite is the abundance of extremely coarsely crystalline, vug-lining white and grey sparry dolomite (Figs.3:5 and 3:6, 4:1 and 4:5). This dolomite was first described from the Pine Point area outcrops and from subsurface by Law (1955b). It has since been reported from subsurface in strata correlative with the rocks of the study area by: Gray and Kassube (1963); Griffin (1965, 1967); Hriskevich (1966), Baillie and Vecsey (1967); Langton (1967); McCamis and Griffiths (1967); Pfaff (1967); Langton and Chin (1968). It has also been reported from carbonates elsewhere (Ney, 1957; Hoagland and others, 1965; Cumming, 1967). The Manitoe Formation of the South Nahanni River area and the Grosmont Formation of northwestern Alberta are also analogous to the Presqu'ile Formation (A.W. Norris, pers. comm., 1970).

The dolomite is interpreted to have formed mainly by the recrystallization of an early, more finely crystalline dolomite (with evaporites in places). Figures 1:5, 1:8, 2:1, 3:5, 3:6, and 4:1 show development of white sparry dolomite around remnants of earlier brown dolomite. In some cases a sequence can be traced from mainly brown dolomite (Fig.1:5) to buff and white dolomite (Fig.1:7). This is interpreted to represent recrystallization of brown dolomite to white dolomite. This probably was

achieved by solution transfer, at least locally, expelling impurities from the new minerals.

Both oxygen and carbon isotopes are similar for both the fine- to medium-crystalline brown dolomites and the coarsely crystalline, buff, white and grey sparry dolomites (Fritz, 1969). Some of the coarsely crystalline dolomite formed by random dolomitization of limestones, as shown in Figs.9:2-9:6. Remnants of limestone are found within the upper part of the coarsely crystalline dolomite facies, but the remnants only rarely are partly dolomitized.

Latticework and boxwork structures (Figs.3:5-3:8) indicate that evaporites interbedded with carbonate may have played a role in the development of the coarsely crystalline dolomite. Other evidence for the presence of abundant sulphate in the carbonate complex during development of this dolomite is shown in Figs.4:6, 7:3, 7:4. Anhydrite (or gypsum) crystals have co-precipitated with coarsely crystalline dolomite in the rocks shown in these illustrations.

Fluid inclusions in the coarsely crystalline dolomite in the orebodies contain fluids with salt contents of 20 equivalent weight percent NaCl (Roedder, 1968a). The temperatures of trapping of the fluid are calculated by Roedder to be in the range 50-100°C. While such determinations have not been made on dolomites throughout the coarsely crystalline dolomite facies, an analogy can be drawn between the similar dolomites within the orebodies and near the orebodies. It is postulated that the white and grey sparry dolomites have formed at least in part by heated basinal fluids passing through the dolomite. Dissolution of earlier-formed brown dolomites and reprecipitation of the material as various vug-lining grey and white dolomite created two generations of dolomite

with almost identical carbon and oxygen isotopes. It has been postulated that the brine that caused recrystallization of the dolomite originated as an oil-field type of brine which moved up the plunging carbonate conduit through the Pine Point area (Jackson and Beales, 1967, p.397). The time of formation of this dolomite is difficult to determine, but it is at least later than consolidation of the overlying Slave Point Formation as some coarsely crystalline dolomite fracture-fillings occur in the basal Slave Point dolomites. The white crystalline dolomite in fractures transects bedding and is later than development of an earlier stage of brown sucrosic dolomite.

Dedolomitization

Dedolomitization is a minor phenomenon at Pine Point. Rarely the coarsely crystalline dolomite has minor dedolomitization to calcite along hair-line fractures. However, in a bitumen-rich zone adjacent to the O42 pit the major portion of a boxwork dolomite, containing bitumen in vugs, has been altered from dolomite to calcite. The cause for this is not known, but it is postulated that it may be related to an excess of calcium from the reduction of sulphates in the presence of bitumen.

SULPHIDE MINERALIZATION

Scattered Sulphides

In addition to the sulphides in orebodies at Pine Point, a number of sulphides occur in a variety of ways throughout the strata. Some of these may be related to the orebodies, but most are not. There are two main groupings: (1) iron sulphides, and (2) lead and zinc sulphides.

1. Iron Sulphides

(a) Pyrite and Marcasite: Both pyrite and marcasite occur extensively

in the study area but because fine-grained pyrite and marcasite are not readily distinguished in hand specimen, all fine-grained iron sulphide has been referred to as pyrite. It occurs throughout the study area in small amounts in all facies, but is more abundant in the dark-green shale facies. In the dark-green shale facies, pyrite occurs as nodules and discrete thin lamellae in shale, as well as disseminated throughout the shale.

Pyrite occurs throughout the dolomites of the Pine Point and Presqu'ile Formations as finely disseminated crystals. Some of the grey-spotted dolomites (Figs.1:1-1:3) owe their colour to very finely disseminated iron sulphide. While some of this may be associated with ore minerals, sulphur isotopes in the pyrite yielded different values (δS^{34}-16.8 to +8.5 for sediments vs. δS^{34} +18.7 for ores) indicating that they are not closely related (Sasaki and Krouse, 1969).

The brachiopod and tentaculitid shells of the bituminous shale, limestone and dolomite member, and the stromatoporoids and corals of the limestone tongues of the Buffalo River Formation are partly replaced by, or contain pore-fillings of pyrite. This indicates that an abudance of iron was mobile during diagenesis of the sediments.

(b) Pyrrhotite: In addition to disseminated pyrite, the Amco marker bed commonly contains elongate pyrrhotite crystals in clusters up to one half inch in diameter. No distribution pattern within the bed has been observed. Pyrrhotite is not the stable form of iron sulphide to form near the sediment-water interface in normal marine environments. It may represent a diagenetic phase connected with heating during ore formation but this is speculation.

2. Lead and Zinc Sulphides

Occurrences of sphalerite and galena that are probably of diagenetic origin are found in each formation in the study area. The bituminous shale, limestone, and dolomite member of the Pine Point Formation contains brachiopods with internal cavities filled with coarsely crystalline sphalerite and galena. The Slave Point Formation contains galena interstitial to intraclasts in an intrasparite bed near the top of the formation.

Scattered small cubes (0.2 mm.) of galena occur in the sparry calcite cement in the white biosparite-pelsparite facies. In the Presqu'ile and Pine Point Formations, scattered small amounts of both minerals are common and may have been formed by the ore-forming processes.

Orebodies

Because of the particular attention focussed on the orebodies at Pine Point, they are treated separately in the following chapter. They are regarded by the writer as an integral part of the diagenetic history of the carbonate complex.

MISCELLANEOUS CHEMICAL DIAGENESIS

Chert and Quartz

Chert and quartz occur only in the Pine Point Formation. The bituminous shale, limestone and dolomite member contains chert nodules 1-2 inches in diameter containing relict outlines of fossil debris. These apparently formed as replacement nodules during diagenesis. Silica was probably derived from skeletons of siliceous organisms such as sponges and diatoms.

Doubly-terminated authigenic quartz crystals 0.2 mm. long make up

1-2 percent of the rock in a medium-crystalline brown dolomite in the vicinity of the X-15 (Pyramid) orebody (Pyramid Hole No. 18 @ 141 feet). The silica for quartz may have been derived from organisms similar to those that form chert, but it may also have originated as wind-blown silt with redistribution during dolomitization.

Fluorite and Barite

A few small crystals of clear fluorite and white to bluish-white barite are found in vugs in the Presqu'ile Formation. As no fluorite or barite is associated with the orebodies, it is assumed that both of these minerals are the products of segregation from carbonates and evaporites during diagenetic changes such as recrystallization and dolomitization. Trace amounts of barium in carbonate minerals could be expelled to form barite.

Bitumen and Oil

Bituminous residues commonly line vugs in all the porous carbonate units, and extreme concentrations (up to 40 percent of the rocks) occur adjacent to at least two of the orebodies. Bitumen typically occurs as droplets and vug-linings on dolomite and calcite crystals. It is often overgrown by both calcite and sulphur. Bitumen also fills intergranular pores in limestones and intercrystalline pores in dolomites. The bitumen is thought to have originated from oil trapped in the rocks prior to mineralization.

Light oil and tarry oil occur in association with bitumen in some dolomite cores, and light oil commonly stains cores in nearly tight limestones, finely crystalline brown dolomites, and compact finely crystalline synsedimentary dolomites.

Native Sulphur

All of the carbonates in the area contain rare to abundant crystalline elemental sulphur. Sulphur frequently fills pores in the Sulphur Point Formation and the basal beds of the Slave Point Formation.

The native sulphur has δS^{34} values of +14.5 to +21.0, comparable to that of sulphates in the area (+17.9) (Sasaki and Krouse, 1969). The associated calcite has very heavy carbon relative to surrounding carbonates (Fritz, 1969). It is thought that the two minerals originated from the complex reduction of sulphate by biogenic activity with resultant precipitation of native sulphur and calcite.

PHYSICAL DIAGENESIS

BIOLOGICAL INFLUENCES

Organisms play an important role in early stages of diagenesis through such processes as chewing, digestion, excretion, burrowing, and mixing of sediments. While the role of these processes can be evaluated in studies of modern sediments, their effects in the present suite of rocks are discernable in only a few rock types. A feature suggestive of burrowing activity of organisms is the mottled appearance of the Amco marker and the compact mottled dolomites occurring above and below it. The mottled effect is due to the presence of finely disseminated iron sulphide and minor bituminous matter.

Micrite rinds and envelopes occur on many of the fine clastic particules in the lagoonal environments and in much of the coarse bioclastic debris toward the north side of the carbonate complex in the Sulphur Point Formation. These have probably been formed by algal boring (Wolf, 1965b, Bathurst, 1966) but as no algal filaments remain, this can only be inferred.

Pellets are a common constituent of rocks of the white biosparite-

pelsparite facies. Undoubtedly, some of them are fecal pellets excreted by organisms. The only change visible in pelleted materials to the petrographer is an increase in grain size, but chemical effects are undoubtedly produced during the passage of sediments through organisms.

COMPACTION

Stylolitization is the only feature observed that indicates compaction in the carbonates of the Pine Point area. This is partly because of obliteration of all details of original particle types in most of the dolostones and some of the limestones. The dearth of compactional features in the carbonates is not usual, as the majority of carbonate rocks have undergone very little compaction (Pray, 1960; Beales, 1965). The solution of carbonates, creating stylolites, does, however, produce a considerable reduction in bulk volume and probably provided much of the calcite for cementation.

Stylolites are very widespread with the most prominent ones occurring in the white biosparite-pelsparite facies, particularly in the pellet-rich rocks, where they have amplitudes up to 10 cm. The coarsely crystalline dolomite facies has stylolites similar to those in the above-mentioned white limestones. In addition, many stylolitic contacts occur between relict Amphipora fragments. The fragments have been reduced to a fraction of their normal size by solution along stylolitic boundaries presumably after dolomitization (Fig.6:8). The coarsely crystalline dolomite facies is severely stylolitized in the interval where the bright green shale facies occurs. Numerous closely spaced stylolites with clay partings presumably developed after dolomitization.

The limestones of the Slave Point Formation have abundant stylolites of small amplitude. The very common closely spaced carbonaceous,

argillaceous laminations are probably all accentuated by solution as in stylolite formation, but the contacts are not very irregular (Fig.8:8). One peculiar feature is the lack of stylolites of any sort in the porous friable brown dolomite facies, except in the laminated brown dolomite but not elsewhere in the facies is perhaps due to lack of enough organic material along the stylolite contact to act as a persistant record of the stylolite through the dolomitization process.

From the present study there is no conclusive evidence that draping of sediments occurred, as the cross sections included in the thesis were drawn using the Amco marker as a time plane. This removed the evidence of any differential compaction between the shales and carbonates, and any draping effect over the carbonate complex. When drawn naturally, the sections show considerable relief on the tops of the carbonate horizons. While most of the relief is due to folding, it may be in part due to differential compaction of the off-reef shaly facies.

FRACTURING

The rocks of the study area have undergone several different periods of tectonic and non-tectonic fracturing. Some phases of fracturing affected solution, porosity development, and localization of orebodies.

Tectonic fractures paralleling minor faults in the area (Norris, 1965, Fig.7) apparently controlled ore deposition to some extent because, as mentioned earlier, the orebodies are elongate in the same direction. These fault trends are, however, at an oblique angle to the basement faults in the area (Norris 1965, Fig.7). Zones of brecciated cohesive dolomite facies and argillaceous dolomitic limestone facies are found at the top of the N42 pit, indicating either collapse or tectonic brecciation with downward movement of fragments.

Fractures that are probably of non-tectonic origin are illustrated in Figs.3:3, 3:5-3:8, and 4:3. Most of these fractures are probably due to solution-slump at varying times during diagenesis. They played a role in porosity development by providing sites for dolomite precipitation for the vertical parts of the latticework structures (Figs.3:7-3:8).

At least two periods of fracturing, of indefinite cause, occurred during dolomitization (Fig.3:4), as the fractures are filled by coarsely crystalline dolomite. Later fractures in the dolomite are filled with sparry calcite.

SURFACE EFFECTS

The role of recent surface solution of the carbonates in the study area is difficult to evaluate, as several periods of surface weathering have probably occurred. Evidence that may indicate earlier exposure to surface effects is as follows:

1. Salina deposits and bedded breccias indicate exposure to some surface effects.
2. Irregular bedding surfaces, rubble zones, vertical fissures filled with green clay, and brackish to fresh-water Charophytes in the bright green shale (Watt Mountain) facies indicates exposure to the influence of fresh-water.
3. Brecciated dolomite and argillaceous limestone overlying ore-bodies indicate brecciation and collapse of overlying strata into the ore zone. This suggests that karst development may have initiated collapse breccias which were later mineralized. However, some of the brecciation in orebodies is post-development of ore so collapse also continued during mineralization.
4. Karst developments filled with glacial debris indicate preglacial

exposure to surface solution. Drilling and development data suggest that this karst system is extensive.

Recent karst or renewed pre-glacial karst development is well manifested in the interbedded evaporites and carbonates (Nyarling Formation) to the south of the study area and extends into the study area. Some of the sinkholes are associated with orebodies that are exposed at surface. Their development may be due to solution of carbonates by acid produced from the weathering or iron sulphides in the orebodies. However, many sinkholes are not associated with ore and are due to solution of carbonates and evaporites.

The abundance of cold sulphur-precipitating springs in the area, particularly along the Buffalo River, indicates circulation of groundwater and reduction of subsurface sulphates. Much of the late pore-filling calcite and sulphur found throughout the study area may have been formed by the action of surface waters bringing hydrocarbon and sulphates in contact for bacterial reduction. Bacterial influence is in evidence as the calcite associated with sulphur is enriched in C^{13} (Fritz, 1969). Crystals of calcite in caverns in the coarsely crystalline dolomite facies are up to several feet in size. Roedder (1968a) determined that the fluid inclusions in them have low salinities and low temperatures of deposition. They may therefore have been deposited from circulating surface waters.

POROSITY DEVELOPMENT

A few points on porosity development are presented here from a qualitative viewpoint, as a quantitative approach is beyond the scope of the thesis. Features that are strikingly manifested or appear to be peculiar to the carbonates of the study area are emphasized.

Bedded Vuggy Porosity in Limestones

Limestones of the basal part of the bedded brown fine-grained limestone facies (basal Slave Point Formation) and the laminated brown limestone and mottled dolomite facies have good vuggy and layered-vuggy porosity. This porosity occurs in a laminated, usually dolomitic limestone of probable algal origin (Fig.4:2). Porosity varies from nil to over 50 percent but averages about 10-15 percent. Some of the vugs are angular, suggesting evaporite solution, but most are irregular and roughly parallel to bedding.

Intercrystalline Porosity

The porous friable brown dolomite facies and the brown dolomite facies of the C marker have good intercrystalline porosity (Fig.3:1) that runs as high as 20 percent (estimated). It is best developed in medium-crystalline idiotopic dolomites, but some occur in hypidiotopic dolomites. Nearly all the other dolomites except the coarsely crystalline dolomite facies have relatively poor intercrystalline porosity or are tight. The coarsely crystalline dolomite facies generally has vuggy porosity (Figs. 4:1 and 4:3) but a few beds with intercrystalline porosity occur (Fig.3:2).

Evaporite-solution and Solution (karst) Porosity

The coarsely crystalline dolomite facies displays a number of features in exposures in pit walls which indicate that some evaporite solution porosity occurs. Some of these features have been described by Beales and Oldershaw (1969). The latticework, boxwork, and bedded vuggy dolomites are illustrated in Figs.3:5-3:8 and 4:1 and 4:3. Evaporitic material, probably mainly anhydrite and gypsum, may have provided a framework support for dolomitization of the material that remains. Evaporites

filled pores thereby preventing their occlusion by calcite or dolomite--the more common fate of pores during carbonate diagenesis.

Another mode of evaporite replacement that eventually created porosity is the replacement of fossils by anhydrite. This occurred in parts of the coelenterate biolithite and rubble facies and in the *Amphipora*-rich southernmost parts of the friable brown dolomite facies. Subsequent solution of some of the anhydrite during and after late-stage dolomitization created some vuggy porosity.

Solution of carbonates, creating karst cavern systems, may be connected intimately with evaporite solution or may be completely independent. The total effect of cavern systems on porosity is difficult to evaluate from the few exposures, but drill hole data indicate an extensive preglacial karst system. The orebodies appear to be localized in part by karst development. Most of the development pits show one or more sinks up to 50 ft. diameter hence the significance of karst systems in determining fluid flow.

Porosity Occlusion

Much of the porosity in dolomites of the area has been completely or partly occluded by white and grey sparry dolomite, sparry calcite, bitumen, and sulphur. Occasionally some anhydrite pore-filling occurs. The sparry dolomite is confined mainly to the coarsely crystalline dolomite facies where it has blocked much of the porosity, creating isolated vugs and lowering the permeability e.g. Figs.1:8, 3:3, 4:1, 4:5, and 4:6. The sparry dolomite probably originated by pressure solution of earlier-formed matrix dolomite since both have similar carbon and oxygen isotopic composition (Fritz, 1969).

Sparry calcite, bitumen, and sulphur occur throughout the limestones

and dolomites of the area, reducing and often completely occluding porosity. Their sequence of deposition (Fig.2:8) is usually bitumen-calcite-sulphur and, as noted in a previous section, the calcite and sulphur are probably due to the bacterial reduction of sulphate in the presence of bitumen.

Anhydrite and gypsum occlude porosity in a few samples from deep holes in the Pine Point and Presqu'ile Formations in the southwest corner of the study area. This material may have migrated with connate or surface water into the carbonates from the intertonguing evaporitic strata to the south.

SUMMARY AND INTERPRETATION OF THE DIAGENETIC SEQUENCE

Diagenesis in the rocks of the study area occurred in three episodes:

1. Early diagenesis following sedimentation involving local fluids and materials; development of burrows, micrite rims on fossil fragments, formation of iron sulphides, early dolomitization, cementation, and replacement of fossils by sulphates.
2. Later diagenesis involving compaction-derived fluids and materials; formation of coarsely crystalline dolomite, possibly preceded by an intermediate stage of brown, more finely crystalline dolomite development. Invasion by bitumen both preceded and followed coarse dolomite development. Ore mineralization accompanied and was followed by coarse dolomite in most ore-bodies. Some ores, however, have little or no associated coarse dolomite.
3. Late effects and surface effects such as karst development, (some of which probably preceded ore emplacement) and precipitation of calcite and sulphur in pores.

There may have been no time gaps between the episodes. In particular, the gap between early synsedimentary dolomite and development of white sparry dolomite may have been bridged by the development of medium-crystalline brown dolomite. This brown dolomite may be partly of synsedimentary origin and partly formed by the channelling of early compaction-derived fluids through the carbonate complex.

Consideration of diagenesis in conjunction with preceding chapters leads to the conclusion that parts of the carbonate complex have been affected by at least four different types of pore-fluids and thus have been subjected to all phases of Fairbridge's (1967a) syndiagenesis-anadiagenesis-epidiagenesis sequence (Fig.16). The four types of fluids are:

1. Connate brines trapped between sediment particles on deposition. These varied from normal marine waters to saturated brines.
2. Heated, concentrated basinal brines moving through the carbonate complex causing late-stage dolomitization.
3. Fresh surface water that penetrated the carbonates during limited exposure in the Middle Devonian, during pre-Pleistocene karst development, and during recent ground-water circulation and karst development.
4. Hydrocarbons that invaded porosity at two different times, the earlier stage being altered to bitumen.

The role played by each of these fluids in diagenesis is difficult to establish but this preliminary study, concentrated on the effects produced, may provide a basis for further study of the processes involved. Isotope and fluid inclusion studies have already yielded results but much more work remains before a reasonably complete understanding of the diagenetic changes is possible.

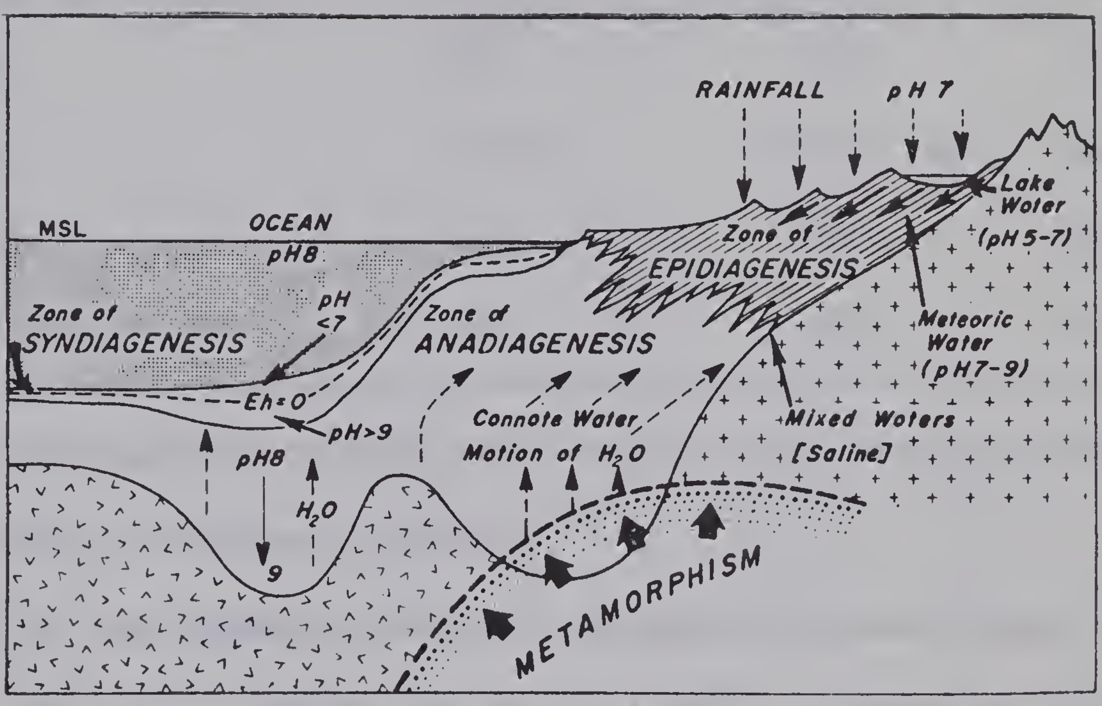


FIGURE 16: IDEALIZED PROFILE THROUGH A CONTINENTAL MARGIN, SHOWING THE SITES OF CONTEMPORARY MARINE SEDIMENTATION AND THE THREE STAGES OF DIAGENESIS (FAIRBRIDGE, 1967a, FIG.4).

CHAPTER 5: OREBODIES

Mississippi Valley-type lead-zinc mineralization of ore tenor occurs as a number of elongate disc-shaped bodies within the Presqu'ile and Pine Point Formations. The total proven reserves of the Pine Point region are 44.4 million tons as tabulated below. A brief summary of the economic development of the ores is given in Appendix A.

Company	Reserves (Millions of tons)	Grade %Pb	%Zn
Pine Point Mines	41.8	2.4	6.3
Conwest-Newconex	1.25	13.0% lead + zinc	
Coronet Mines Ltd.	1.1	2.7	10.4
Yellowknife Base Metals Ltd.	0.3	1.74	6

Production data and reserves of Pine Point Mines Ltd., the only producer in the area to date, are shown in Table 5.

The geology of the deposits has been discussed in some detail by Campbell (1966, 1967) and Jackson and Beales (1967). Extensive bibliographies of publications on Pine Point are found in Campbell (1966) and Beales and Jackson (1968). Subsequent papers dealing with fluid inclusion work and ore textures have been published (Roedder, 1968a,b). Additional references to isotope and trace element data are: Jeffs (1955), Robertson (1966), Sangster (1968a,b), Evans, Campbell and Krouse (1968), White (1968), Billings, Kesler and Jackson (1969), and Cameron (1969). A group of papers has been published on the sulphur, carbon, oxygen, and lead isotopes of the ores and host rocks (Jackson and Folinsbee, 1969; Fritz, 1969; Sasaki and Krouse, 1969; and Cumming and Robertson, 1969). Porosity and permeability data on the host rocks can be obtained from a paper on

TABLE 5: PINE POINT MINES LTD. PRODUCTION, EARNINGS, AND RESERVES 1964-1968

YEAR	RESERVES	GRADE		PRODUCTION			SALES	NET EARNINGS
	(m. tons.)	%Pb	%Zn	TONS	%Pb	%Zn	(CANADIAN DOLLARS)	
1948-1953	5 million ±	4.0	7.0					
1964	2 months	production			18.6	25.8	1,057,000	(invest. income deducted)
1965	21.5	4.0	7.2	75,356	4.27	7.63		
				364,168	22.5	29.1		
							26,482,000	22,132,000
1966	37.8	2.9	6.8	1,457,990	4.9	10.5	22,085,000	
	Direct shipping ore (340,000 tons?)						20,551,000	
							42,636,000	34,194,000
1967	40.5	2.6	6.8	1,521,000	4.7	9.7	24,675,000	
				333,000	18.0	27.9	18,026,000	
							42,701,000	34,232,000
1968	39.3	2.6	6.8	2,138,000	3.5	6.6	21,154,000	
				353,000	19.0	25.0	18,759,000	
							38,913,000	21,029,000
1969	41.8	2.4	6.3	3,605,000	3.2	7.4	42,917,000	17,875,000

SOURCE: FINANCIAL POST SURVEY MINES; PINE POINT MINES LTD. FINANCIAL STATEMENTS.

dewatering of the ore zones (Calver and Farnsworth, 1969).

The ore minerals are galena and sphalerite associated with abundant pyrite and marcasite with very minor pyrrhotite. Weathering products such as anglesite, cerussite, goethite, native sulphur and gypsum occur in orebodies exposed at surface but are not found in deeper orebodies. The ore minerals occur in bodies from 100,000 tons to several million tons in size. Some large barren marcasite bodies and smaller non-economic lead-zinc bodies also occur. The orebodies are usually elongate, lenticular in plan, flat-lying in vertical section, with sharp margins on all sides. Approximate dimensions of some orebodies opened by initial mining operations are 1,200 feet long by 400 feet wide by 200 feet deep, but considerable variation in shape occurs. The elongation in the same direction for each orebody is thought to be due to a combination of regional structural trends, and local stratigraphic trends with minor lithologic variations in conjunction with minor faulting and fracturing.

The orebodies occur throughout the Presqu'ile and the upper part of the fine-grained dolomites of the Pine Point Formation. Several different facies contain orebodies. Some coelenterate biolithite and rubble facies material is mineralized along the north margin of the carbonate complex. Other facies containing orebodies that have been exposed by open pit mining include: the white biosparite-pelsparite facies, the bright-green shale facies, and the latticework dolomites and boxwork dolomites of the coarsely crystalline dolomite facies. The Pyramid (X15) orebody has wallrock of laminated brown dolomite of the friable brown dolomite and cohesive brown dolomite facies, and some coarse breccia (solution breccias)? of the cohesive brown dolomite facies.

The orebodies have remarkable sharp margins even though the porosity

in the immediately adjacent wallrock is extremely vuggy to cavernous. All ore zones opened by pitting operations to date have a brecciated zone of dolomite (and argillaceous limestone in some orebodies) overlying and associated with the ore, suggesting that the orebodies occupy what were at one time collapse-breccia zones. Some of the breccia fragments are from higher stratigraphic levels than their present position.

A considerable body of data regarding the host rock and orebodies has been accumulated. These data strengthen to some extent an earlier proposed hypothesis that the ores are of diagenetic origin and are formed from materials derived from an evolving sedimentary basin (Jackson and Beales, 1967). This hypothesis only is investigated here, as the possibilities of a magmatic hydrothermal or syngenetic origin have been previously considered (Beales and Jackson, 1968). The approach of this section then is to investigate to what extent the additional data support or negate the earlier hypothesis.

In considering the origin of the ores it is necessary to explain:

1. the source of the metals
2. the source of the sulphur
3. the mode of transport
4. the cause of precipitation and localization into orebodies.

Source of Metals

Lead isotope data (Appendix D, No.1) do not yet permit definite conclusions regarding the source of lead in the ores. Cumming and Robertson (1969) conclude that the lead came from a homogeneous source with a model age of about 250-275 million years. This is considerably younger than the Middle Devonian host rocks (about 350 million years). Further analyses (Appendix D, No.2-10) have not been corrected for lead-204 scatter and runs

have given inconsistent results (D.K. Robertson, pers. comm. 1969).

However, if the uncorrected results (Nos.2-10) are accepted as approximate values, then it appears possible that the lead in the ores could have been derived by leaching of lead from the sediments. Several of these measurements were made on lead sulphides of probably diagenetic origin. Doe, Hedge, and White (1966) have indicated that fractionation of lead can occur during leaching of lead from sediments by hot brines. When one considers the possibilities of fractionation in conjunction with the variations of lead isotopes within modern sediments (Chow and Patterson, 1962) then it is not unrealistic to expect fractionations of the order necessary to produce the age difference indicated by these preliminary analyses. The segment of the sedimentary pile from which the lead was leached would, however, have to have similar U/Th/Pb ratios to the mantle. Certainly, present data do not rule out a source of lead within the sedimentary pile.

The earlier hypothesis that the metals were derived from the sedimentary pile to the west has been supported by chemical data. Cameron (1969) has demonstrated that the Slave Point carbonates of northeastern British Columbia have a significant increase in zinc content (as sphalerite) in a zone along the facies front. Cameron (1969, p.265) concluded -- "Slave Point carbonates do not presently contain significant amounts (15 ppm) of non-sulfide zinc, which might have served as a source for the sphalerite. It seems more likely that the zinc came from the shale basin."

Investigation of brines in the Zama and Rainbow Lake oil-fields of northwestern Alberta has revealed the presence of significant amounts of zinc in the brines (Billings, Kesler, and Jackson, 1969). Zinc contents of 40 brine samples averaged 18.9 ppm and ranged from 0.01 to 290 ppm.

These brines lie in strata laterally equivalent to the southwestern extension of the carbonate complex of the study area (McCamis and Griffith, 1967) (see Fig.1A). The fluid drive from these oilfields is to the east toward Pine Point (Brian Hitchon, Alberta Research Council, pers. comm. to G. K. Billings).

If Cameron's conclusion that the metals in the carbonate horizons were derived from adjacent shales is pursued, the question arises of the availability of metals in the shales. Beales and Jackson (1966) noted the general availability of metals in shales. Williams (1967) demonstrated that metals can be leached from outcrop samples of Alberta shales with distilled water and 1 N ammonium acetate at pH^8 (24 hours for each treatment). The mean value for the combined values from the two solutions (ppm of rock) from 82 samples were: Zn 8.3, Cu 2.1, Fe 61, Mn 11.

Billings, Kesler and Jackson (1969) have calculated that the pore fluids within the downdip extensions of the carbonate complex that outcrops at Pine Point, contain sufficient metal to form half the postulated ultimate reserves of the Pine Point area (7.5×10^6 tons of zinc). Taking into account the possible area and volume affected, adequate amounts of metals to form the deposits are thus readily available within the sedimentary pile if a driving and concentrating mechanism operates on them.

Source of Sulphur

An extensive study of S^{34}/S^{32} ratios in sulphides, sulphates, elemental sulphur, and pyrobitumen in and contiguous to the lead-zinc ores (Sasaki and Krouse, 1969) allows some conclusions to be drawn with regard to the source of sulphur in the ores. The values are tabulated in the table on the following page.

Material	δS^{34} Values
Sulphides in ores	+20.1 ± 2.6 (118 samples)
Diagenetic sulphides	+9.0 to -18.8
Sulphur in bitumen	+3.3 to +7.0
Native sulphur from vugs	+14.5 to +21.0
H_2S from Rainbow oilfield gas plant	+9
Sulphates from N. Alta. oilfield brines	+16.2 to +19.1
Evaporites contiguous to carbonates	+19 to +20
Surface cold springs: sulphate	+20.4
H_2S, S^o	-11.0 to -13

(Sasaki and Krouse, 1969)

The similar isotopic composition of sulphur in the sulphides in ore zones, native sulphur in vugs, sulphates from correlative strata, and sulphates in cold surface water springs indicates that the sulphur in all of these had a similar origin. Devonian sea water sulphate was apparently the ultimate source of the sulphur and the immediate source was probably the sulphates associated with the carbonate complex. The mechanism of reduction from the sulphate form to sulphur without fractionation, for incorporation into the ores is a matter of debate (Sasaki and Krouse, 1969). Either complete reduction of the sulphate, or reduction to H_2S with fractionation and subsequent homengenization could explain the consistent values obtained. It seems unlikely that the sulphur could have had a 'deep-seated' magmatic source.

Mode of Transport

The nature of the ore-forming fluid can be deduced from analyses of fluid inclusions in the orebodies. Roedder (1968a) concluded that the

ore-forming fluid was highly saline, from 20-30 percent salts by weight. The temperature of deposition of sphalerite in the ores, as deduced from fluid inclusion data, varied from 50-100°C. However, Vasquez (1968), using fluid inclusions, found somewhat higher temperature values for both calcite and sphalerite.

The $\Delta\delta S^{34}$ values for sphalerite-galena pairs suggest a temperature value of between 175-200°C. using this recently established geothermometer. More precisely, G.K. Czamanske (personal communication, 1970) obtained a value of 192°C. when using the average $\Delta\delta S^{34} = 3.2$ for the Pine Point ores (Sasaki and Krouse, 1969, Table 1) and 171°C. when the value for concentrates ($\Delta\delta S^{34} = 3.5$) is used.

These values are higher than those determined by fluid inclusion studies. There are still problems to be resolved regarding this geothermometer, as various workers (Grootenboer and Schwarz, 1969, Kajiwara, 1969, and Rye and Czamanske, 1969) obtain conflicting results in experimental determinations. Czamanske (personal communication, 1970) indicated three possible explanations for the discrepancy between the two geothermometers:

"1. the calibration cannot be extrapolated linearly to lower temperatures ----------

2. the equilibrium values may depend in some unexpected way on the chemistry of the solution, e.g. the means of metal transport and removal at the crystal interface

3. precipitation may have been too rapid for equilibrium values to be realized."

It can thus be concluded that the ore-forming fluid was a hot brine. The chemical composition of this brine is currently being examined by

H. Ohmoto at the University of Alberta. Brines of similar salinities and temperatures are found in the Rainbow Lakes oilfield to the southwest of Pine Point (Billings, Kesler, and Jackson, 1969) and it must be considered that similar brine escaping through the carbonate complex may have been the ore-transporting fluid. Similar hot metal-bearing brines may have been reported from other areas (White, 1968; Lebedev, 1967).

Cause of Localization

The source of ore materials and the nature of the fluid at the time of precipitation of the ores can be evaluated to some extent from chemical data. However, the cause of localization of the orebodies is more obscure. This problem has been discussed at length by Jackson and Beales (1967) and Roedder (1968a).

Each orebody in the Pine Point area has an associated brecciated zone, overlying and passing into the wall rock from the orebody. Whether these breccias are a cause of, or a result of, ore localization is still open to question.

Mixing of two fluids (one derived from depth, the other from near surface) has been proposed as an ore precipitating mechanism by Beales and Jackson (1966) and Roedder (1968a). This mechanism can explain the sharp margins on the orebodies, even where porosity continues. A heated brine bearing metals derived from the basin to the west could form a sharp interface with a hydrogen sulphide-bearing cool surface water. Deposition of sulphides would occur only where the fluids mixed. The net inflow of fluid into the ore zone (porous brecciated area) from the carbonate would prevent disseminated mineralization from forming around the ore zones.

<u>Origin of the Ores</u>

The data collected to date are consistent with the derivation of the ore materials from sediments during diagenesis. Heated compaction-derived metal-bearing brines from the shale-carbonate sequence to the west could have moved up-dip through the carbonate complex to the vicinity of Pine Point. Mixing of this brine with hydrogen sulphide gas or hydrogen sulphide-bearing surface water would have caused precipitation of sulphides.

Localization of the ores would thus be dependent on:

1. On a broad scale, the channelling of basin-derived brines through the barrier complex up-dip toward Pine Point.
2. The channelling of these fluids through more permeable zones within the carbonate complex, such as breccia zones, fracture and fault zones, initial porosity trends, diagenetic porosity trends, and paleo-karst systems.
3. The generation of sufficient sulphur within the carbonate complex to precipitate the metals. Extensive surface deposits of sulphur along the Buffalo River in the study area and along the Peace River in northern Alberta attest to the production of sufficient sulphur by local reduction of sulphate.
4. The mixing of the basin-derived brine with the sulphur either through leaking of hydrogen sulphide from a reservoir or by the mixing with near-surface waters carrying the sulphur.

Point (2) is probably the controlling factor on the variation between individual ore bodies, but the role played by the various types of permeable zones requires much more investigation before final conclusions can be drawn. Additional open pit exposures will presumably permit a proper evaluation of each of the porosity controls.

CHAPTER 6: INTERPRETATION OF THE GEOLOGICAL HISTORY PINE POINT AREA

The geological history of the Pine Point area during the Paleozoic and later can be summarized in three stages:

1. Deposition of the Middle Devonian Chinchaga and earlier evaporitic and clastic sediments on the Precambrian basement.
2. Reef-bank development during the Middle Devonian.
3. Events subsequent to the Middle Devonian.

1. Deposition of Chinchaga and Older Sediments (Fig.17A).

Sediments overlying the Precambrian basement up to the top of the Middle Devonian Chinchaga Formation consist essentially of clastics, evaporitic red bed sequences, and evaporites of Ordovician and possibly Cambrian age (Rice, 1967, p.9). Early evaporites were deposited in three separate basins and are succeeded by the later Chinchaga evaporites that were deposited in one widespread basin. Their presence indicates the existence of a hot arid climate in the area for some time (Fairbridge, 1967b, p.403).

2. Reef-bank Development.

i. Bank Initiation and Migration--basal beds of the Pine Point Formation (Fig.17Bi).

After a transgression of the sea that provided normal marine water over the area compared to previously restricted conditions, carbonate beds accumulated over a wide area. Arching or minor faulting roughly parallel to the northeast-trending extension of the East Arm Fault zone allowed organisms, mainly a crinoid-brachiopod assemblage, to begin growth on the widespread carbonate shelf.

ii. Development of the main barrier reef-Pine Point Formation (Fig.17Bii).

After reef initiation on a bank or platform of crinoid-brachiopod debris, the reef developed into a northeasterly-trending barrier carbonate complex (Fig.1A). Due to scanty well control at depth it is difficult to determine the relief attained on the organic barrier relative to the fore-reef basin. However, a northwest to southeast sequence developed consisting of argillaceous bituminous limestone containing Lingula, Tentaculitids, and crinoids; fore-reef talus with horn corals, brachiopods, Thamnopora, some crinoids and some platy stromatoporoid fragments; organic reef with platy and subspherical stromatoporoids, thick-shelled brachiopods and some horn corals; reef-derived rudites and arenites with some Stachyodes and a few Amphipora. The arenites grade southward into Amphipora-rich lagoonal and laminated (algal) deposits with abundant calcispheres and nodular gypsum/anhydrite, and eventually into interlaminated anhydrite and dolomite of the evaporite basin.

This general configuration persisted until influx of the shale of the Buffalo River Formation when the reef retreated southward initially. Then the reef, within a few feet of section, migrated northwest perpendicular to the barrier trend as much as five miles over the shale to just south of the south shore of Great Slave Lake. Subsequent deposition consisted of a fore-reef shale with limestone tongues, reef carbonates, and a back-reef evaporite sequence (Fig.17Bii).

The end of this phase of deposition was marked by a period of partial or total emergence of the reef (due possibly to tilting) with leaching and development of a bedded breccia horizon, the D3 marker.

iii. Development of the sabkha-surfaced banks (Fig.17Biii).

Presqu'ile Formation, part of the Sulphur Point Formation, and part of the Buffalo River Formation

After minor transgression of seas, accumulation of the carbonate complex continued but the organic barrier developed only sporadically along the northern margin of the barrier complex and scattered patches of Thamnopora and horn corals, and minor stromatoporoid buildups occupied the position of earlier massive and platy stromatoporoid organic reef development. The subdivision into fore-reef shale, fore-reef clastics, supratidal skeletal shales and scattered organic reef patches, bank and mudflat complex persisted throughout deposition of the formation. The mudflat complex was composed of intertidal and supratidal algal flats, salinas, sabkhas, and Amphipora lagoons grading into and intertonguing with the gypsum/anhydrite of the back-reef evaporite basin.

Two periods of tilting toward the north, or regression and partial exposure creating sabkha-like environments, are marked by the development of the C marker dolomite horizons. Other periods of minor exposure to weathering may have occurred, but they have not left a persistent record.

Early dolomitization of the Presqu'ile occurred during accumulation, possibly by a reflux mechanism. The coarsely crystalline dolomite did not form until later, creating a diagenetic unit--the coarsely crystalline dolomite facies--which has boundaries that cut across the sedimentary layering in places.

iv. Subsidence and deposition of shallow marine bank deposits comprising the Sulphur Point Formation up to the top of the bright-green shale facies, part of the Buffalo River Formation, and most of the non-laminated brown limestone and dolomite facies.

The sedimentary environmental setting during deposition of these strata was basically the same as during phase (iii) deposition (Fig.17Biv) except that fewer evaporites were developed within the lagoonal complex. The organic reef was sporadic and shifted northward to the south shore of Great Slave Lake, in which position most of the uppermost part of the white biosparite-biopelsparite accumulated (just prior to deposition of the bright-green shale facies).

In the latter part of this phase of development a number of lenses of bright-green clay (Watt Mountain) were deposited over the carbonates on disconformity surfaces and washed into pockets, channels, and vertical fissures extending to depth. The sea regressed northward numerous times with resultant intermixing of brackish water shales with charophytes and marine limestones in the upper part of this interval. Salinas developed allowing deposition of gypsum with pelleted lagoonal muds and green clay during the latest part of this phase of deposition (Fig.A6). The end of this phase marks the end of barrier development in the study area. The barrier may have undergone prolonged exposure at this time.

v. Deposition of predominantly restricted lagoonal flat to supratidal sediments--the Fort Vermilion Formation. This phase includes: the laminated limestone and mottled dolomite facies, the upper part of the non-laminated brown limestone and dolomite facies, the gypsiferous limestone/dolomite facies, the lower part of the bedded brown fine-grained limestone facies, and the mottled dolomite facies.

Following breakdown of the barrier, a widespread sequence of supratidal, intertidal and shallow subtidal sediments reflect shallow transgression of the sea with one major transgression that resulted in

deposition of the sediments of the argillaceous dolomitic limestone facies (Amco marker). (See Fig.17Bv).

Supratidal mudflats and sabkha-like environments predominated and deposition produced algal-laminated limestones, dolomitic limestones and mottled synsedimentary dolomites containing lenses 20-30 feet thick by one half mile in diameter of gypsum/anhydrite interlaminated with dolomite. These are best developed in the area of the Buffalo River (Fig.A6). There is no sharp boundary to the end of this phase of restricted deposition, but more open marine limestones were deposited over all of the rock types described above.

vi. Subsidence, shallow sub-tidal deposition and migration of the carbonate front--upper part of the Slave Point Formation.

The barrier reef or patch reefs did not persist into the Slave Point in the study area, but rather a marine transgression resulted in widespread carbonate deposition which blanketed the older sediments.

Periods of partial restriction did occur giving rise at times to a restricted fauna of small brachiopods, small Amphipora and ostracods. Algal mat deposition also recurred and other phases of shallow water deposition are indicated by intraclast zones in both the lower part and the uppermost part of the formation.

This phase of deposition was terminated by a major marine transgression which resulted in deposition of argillaceous material (Upper Devonian Hay River shales) over the various carbonates of the Slave Point Formation.

3. Events subsequent to the Middle Devonian.

Since deposition, the carbonates of the area have been tilted gently

to the west and have undergone karst development, and severe late-stage dolomitization associated in part with sulphide mineralization. The barrier reef complex which accumulated on a relatively flat surface now plunges gently (about 20 feet per mile) toward the southwest. The deformation took place in post-Devonian time, during the late Paleozoic and Mesozoic. Some faulting occurred in the area, possibly in the post-Presqu'ile pre-basal Hay River interval (Norris, 1965, p.88). Most of the fault movements were presumably later but their age has not been established.

Most of the dolomitization was probably penecontemporaneous. However, a later phase of dolomitization created the coarsely crystalline dolomite and white sparry dolomite of the Presqu'ile Formation. This late alteration is thought to have been associated with thermal waters escaping through the reef conduit from fore-reef shale sequences further down the plunge to the west, (Jackson and Beales, 1967). Tilting of the barrier and deposition of late Paleozoic and Mesozoic sediments on top of the shales caused this fluid migration. These thermal waters caused some dolomitization of Sulphur Point limestones, but the main effect was the recrystallization of earlier-formed dolomite and precipitation of several stages of coarsely crystalline grey and milky white dolomite in vugs and fractures. Deposition of the lead-zinc ores accompanied this later phase of dolomitization. However, the ores are not confined to strata with the coarsely crystalline white dolomite. The final configuration of the coarsely crystalline dolomite is shown on Fig.17C.

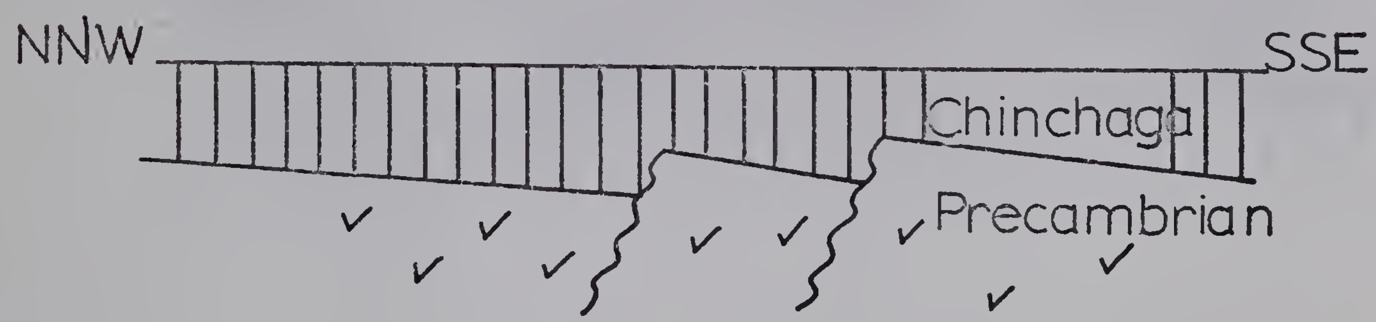
Karst topography developed in the area prior to the Wisconsin ice advance and possibly much earlier. It would not be possible to differentiate earlier stages of karst development from pre-glacial and modern

phases with the data presently available. Weathering probably occurred at the end of deposition of the bright-green shale facies. Another prolonged period of exposure occurred in pre-Cretaceous time after the barrier had been tilted toward the west, and karst development could have been renewed in the exposed eastern end of the barrier at Pine Point.

Sinkholes related to the karst development in the Pine Point area where the carbonate complex outcrops, are filled by glacial and possibly some pre-glacial debris. Host rock and orebodies were polished and abraded by the ice. Sinkhole development continues today in the carbonate and carbonate-evaporite units.

FIGURE 17: STAGES OF DEVELOPMENT OF THE CARBONATE COMPLEX, PINE POINT AREA. DIAGRAMMATIC, NOT TO SCALE, GREATLY EXAGGERATED VERTICALLY. ALL SECTIONS ARE ORIENTED AS IN (A). SL.= SEA LEVEL.

(A) DEPOSITION OF CHINCHAGA AND OLDER SEDIMENTS ON THE PRECAMBRIAN BASEMENT.



(Bi) BANK INITIATION IN PLATFORM LIMESTONES -- BASAL PINE POINT FORMATION.

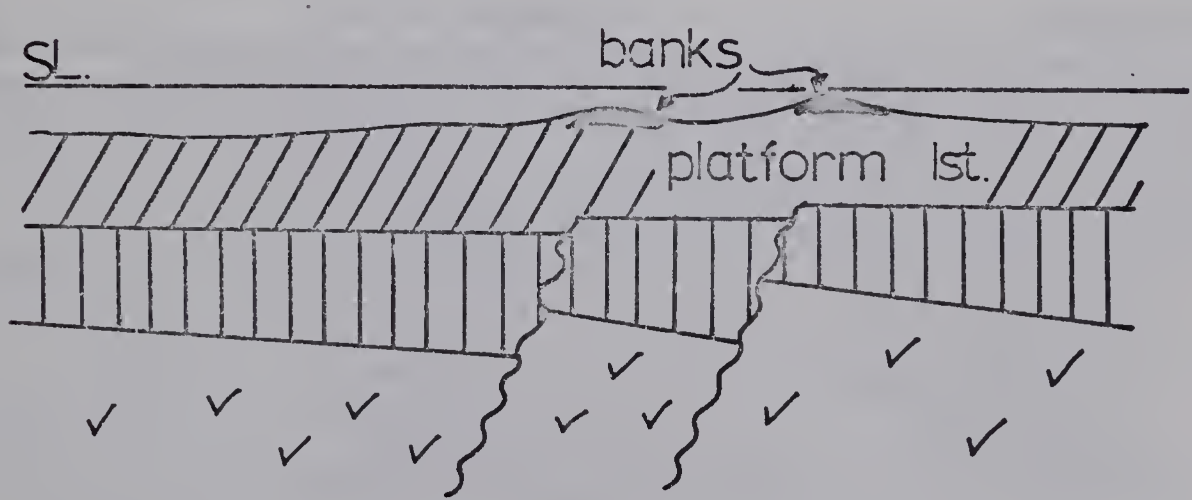


FIGURE 17 (CONT'D)

(Bii) DEVELOPMENT OF THE BARRIER REEF -- PINE POINT FORMATION.

(Biii) DEVELOPMENT OF THE SABKHA- SURFACED BANK -- PRESQU'ILE FORMATION AND PART OF THE SULPHUR POINT FORMATION.

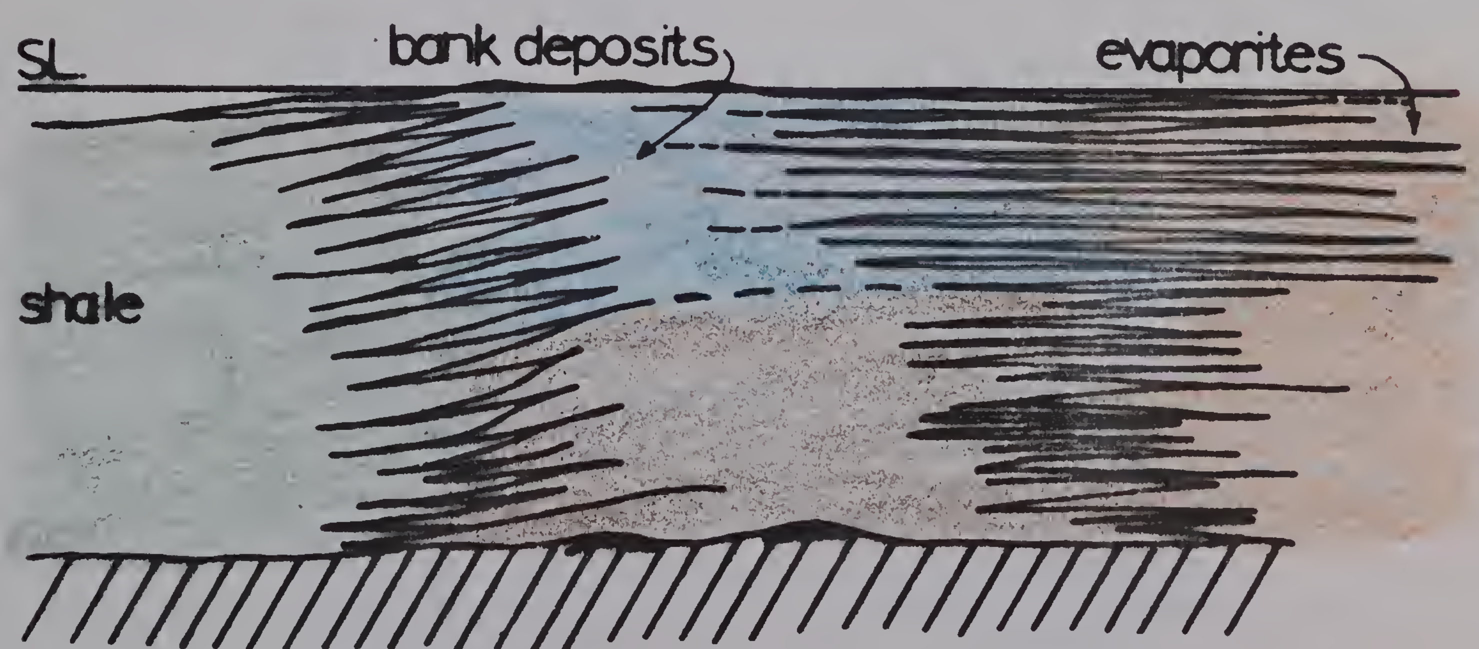
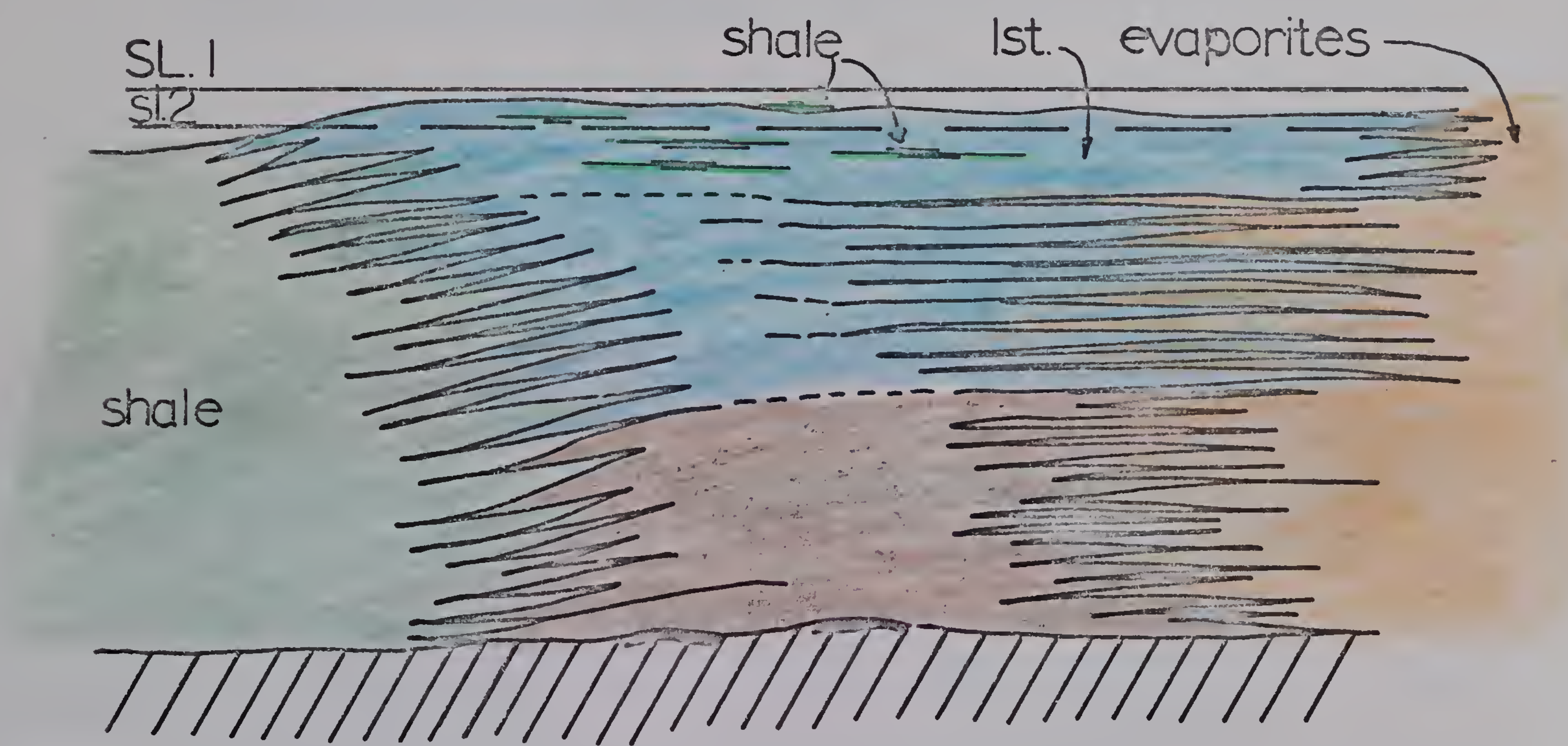


FIGURE 17 (CONT'D.)
(Biv)
SUBSIDENCE AND DEPOSITION OF SHALLOW MARINE BANK DEPOSITS -- UPPER PART OF THE SULPHUR POINT FORMATION. SL1= sea level for main unit; SL2 = sea level for the bright-green shale facies.



(Bv) DEPOSITION OF RESTRICTED LAGOONAL FLAT TO SUPRATIDAL SEDIMENTS -- THE FORT VERMILION FORMATION. SL1 = sea level; SL2 = sea level for Bvi phase of deposition (Slave Point Formation).

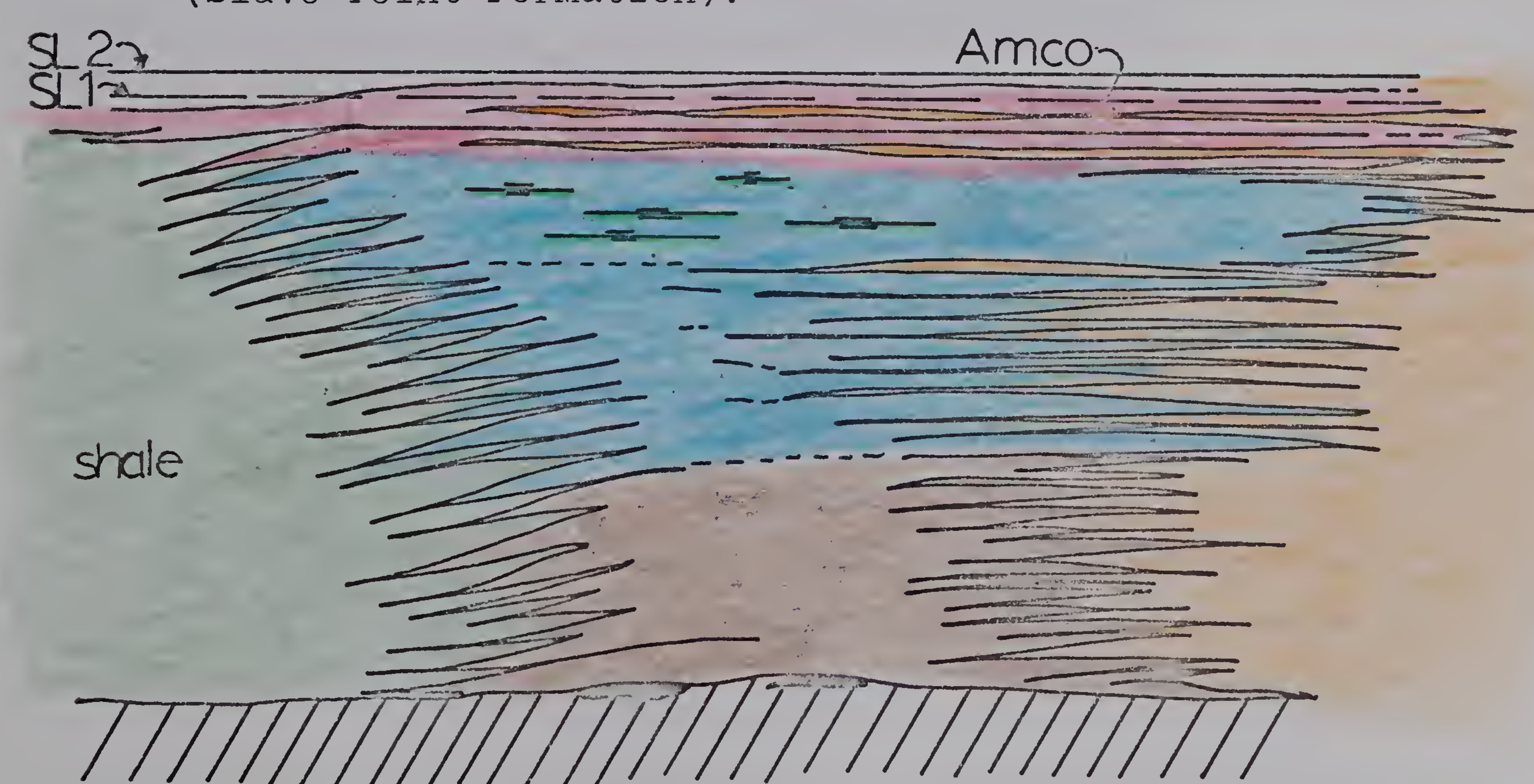
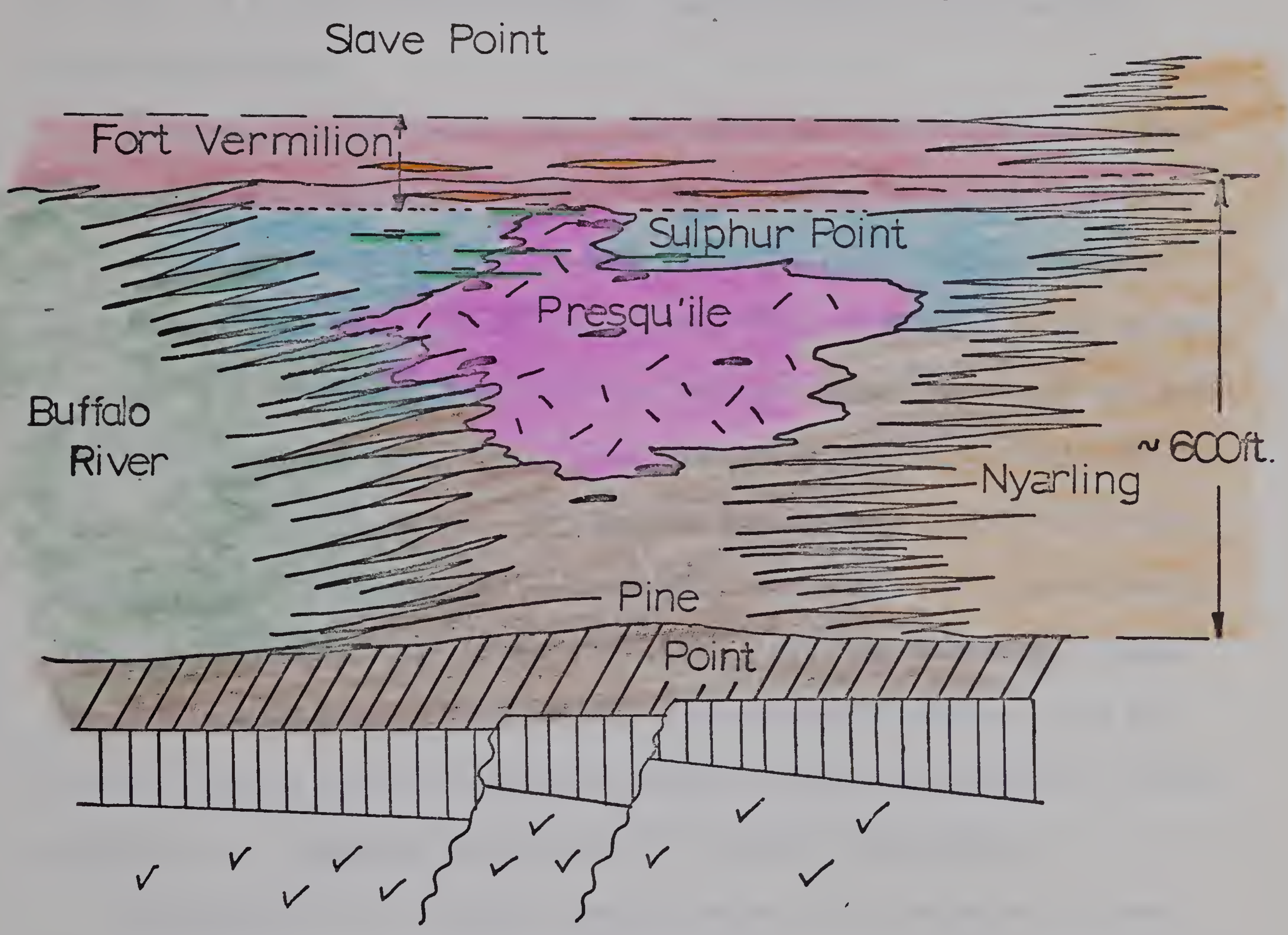


FIGURE 17 (CONT'D.)

(C) EVENTS SUBSEQUENT TO THE MIDDLE DEVONIAN--LATE-STAGE DOLOMITIZATION, LEACHING, AND MINERALIZATION WITH LEAD-ZINC ORES ( ). KARSTING AND LATE-STAGE FAULTING NOT SYMBOLIZED.



CHAPTER 7: CONCLUSIONS

The Middle Devonian carbonate rock accumulation in the Pine Point area is in part a barrier bank complex. This barrier carbonate is overlain by extensive shelf-type carbonates. In its early stages, the barrier carbonate complex developed in a manner similar to the isolated Devonian carbonate reefs and reef complexes of Alberta, such as the Redwater reef, the reefs of the Swan Hills Formation, and the reefs of the Zama and Rainbow Lake areas.

A sequence of fore-reef, reef, and back-reef lithologies and faunas is clearly recognizable in the Pine Point Formation but is more obscure in the younger Presqu'ile and Sulphur Point Formations. The fringing barrier reef that developed during the Pine Point Formation broke up into a series of isolated patches along the northern margin of a bank and mudflat complex during deposition of the Presqu'ile and Sulphur Point Formations. The former back-reef environments migrated northward toward the barrier front. This produced an interplay of two types of predominantly carbonate sediments: (1) those deposited in lagoons, intertidal zones, supratidal pools and salinas, sabkhas and supratidal mudflats, and (2) clastics derived from the scattered reefal and bank developments or from organisms e.g. Amphipora growing in the lagoonal environment.

Development of the barrier complex ceased after exposure to fresh and brackish water conditions during deposition of several bright-green argillaceous beds (Watt Mountain) over the carbonates. Subsequent carbonates of the Fort Vermilion and Slave Point Formations blanketed the study area. Local areas of restriction and evaporite deposition formed but no major divisions into fore-reef, bank/reef, and back-reef developed.

Several conclusions of the stratigraphy of the complex have been

reached from this study:

1. The Amco 'shale' forms a good marker over much of the study area, can be used as an approximate time line for reconstruction of reef development, and is a tongue of the Buffalo River Formation.
2. The Buffalo River unit is reinstated as a formation. It is laterally equivalent on the north to not only the Pine Point Formation, as previously established, but also to the Presqu'ile Formation and part of the Sulphur Point Formation.
3. The Watt Mountain shale of this area, while forming a useful marker, should be considered a facies of the Sulphur Point Formation since the shale beds are discontinuous, lenticular and vary in number and stratigraphic position.
4. The Fort Vermilion Formation (Law, 1955a,b; Norris, 1963, p.59) is recognized in the study area. This solves (a) the problem of correlation of strata formerly placed in the upper Sulphur Point and lower Slave Point Formations with other areas, and (b) the problem of leaving some of these strata unclassified or differently assigned.

The oxygen isotope content and $CaCO_3$ content of dolomites of the Fort Vermilion Formation might be sufficiently distinctive for recognition and correlation of this formation.

Diagenetic alteration of the carbonates has been extensive. Penecontemporaneous dolomitization and late-stage dolomitization associated with lead-zinc sulphide mineralization are the most striking features. The Pine Point and Presqu'ile Formations are thought to have both been dolomitized penecontemporaneously by dense magnesium-enriched brines from lagoons and salinas refluxing through the sediments of the barrier complex.

Extensive brine-producing intertidal and supratidal areas were conducive to continued dolomitization throughout development of the barrier complex. Possibly the dolomite-producing areas on Bonaire, Netherlands Antilles, (see Murray, 1969) provide a modern analog of this ancient environment.

The early dolomite and some limestone of the Presqu'ile Formation were extensively altered to coarsely crystalline secondary white and grey dolomite. The alteration was caused in part by warm brines moving through the Presqu'ile barrier recrystallizing earlier-formed dolomite and also by dissolving and reprecipitating the dolomite in voids as white and grey 'vein' dolomite. Some of the Presqu'ile dolomite was probably formed by dolomitization of Sulphur Point limestone by the warm late-stage brines.

Lead-zinc sulphide mineralization is in part associated with the late-stage dolomite. The ores are epigenetic in nature. Porosity trends created by such processes as brecciation, tectonic movement, karst development, and evaporite solution, have in part controlled the concentration of the mineralization. Sulphur isotope data indicate that the sulphur in the sulphides of the orebodies was derived from the evaporites associated with the carbonate complex. Lead isotope data do not yet indicate conclusively the origin of the metals.

Evaporite solution phenomena such as vugs after gypsum/anhydrite nodules and rosettes are important contributors to the porosity of the carbonates of the study area. Some of the boxwork and latticework structures may be due to evaporite solution also. Reduction of sulphate in pore fluids has resulted in porosity-choking calcite and sulphur. Similar porosity-creating and occluding processes can be expected in other porous carbonates that are associated with evaporites.

REFERENCES

Adams, J.E., and Rhodes, M.L., (1960), Dolomitization by seepage refluxion: Am. Assoc. Petroleum Geologists Bull., v.44, no.12, p.1912-20.

Ager, D.V., (1963), Principles of paleoecology: McGraw-Hill Co. Inc., Toronto, p.371.

Alberta Society of Petroleum Geologists, (1964), Geological history of western Canada, R.G. McCrossan and R.P. Glaister, eds., p.232.

Audretsch, A.P., (1967), A Middle Devonian Microflora from the Great Slave Lake area, Northwest Territories, Canada in Internat. Symp. on the Devonian System, Calgary, 1967, D.H. Oswald ed., v.II, p.837-847.

Baadsgaard, H., Campbell, F.A., Cumming, G.L., Evans, T., Kanasewich, E., Krouse, R.H., Robertson, D.K., and Folinsbee, R.E., (1966), Isotopic data from the Cordillera and Liard Basin in relation to the genesis of the Pine Point lead-zinc deposits: Roy. Soc. Canada, June Meeting, 1965, abstract.

Baillie, A.D., and Vecsey, G.E., (1967), Metamorphism in a Middle Devonian reef complex, northeastern British Columbia, Canada: Int. Symp. Devonian System, Sept. 1967, abstract: Alta. Soc. Petroleum Geologists Calgary.

Baragar, W.R.A., (1964), Geology of the lead-zinc deposits: North, v.11, no.3, p.18-22.

Bassett, H.G., and Stout, J.G., (1967), Devonian of Western Canada, in Internat. Symp. on the Devonian System, v.1, Alta. Soc. Petroleum Geologists, Calgary, p.717-752.

Bathurst, R.G.C., (1966), Boring algae, micrite envelopes and lithification of molluscan biosparites: Geol. Jour., v.5, p.15-32.

Beales, F.W., (1960), Limestone peels: Jour. Alta. Soc. Petroleum Geologists, v.8, no.4, p.132-135.

_______________, (1965), Diagenesis in pelletted limestones in Dolomitization and limestone diagenesis: Soc. Econ. Paleontologists and Mineralogists, Spec. Pub. no.13.

Beales, F. W., and Jackson, S.A., (1966), Precipitation of lead-zinc ores in carbonate reservoirs as illustrated by Pine Point ore field, Canada: Inst. Min. Met. Trans., v.75, p.B278-285; discussed in v.76, 1967, p.B130-136, p.B175-176.

_______________, and Jackson, S.A., (1968), Pine Point - A stratigraphical approach; Can. Inst. Min. Met., v.61, no.675, p.867-878.

Beales, F.W., and Oldershaw, A.E., (1968), Evaporite-solution brecciation and Devonian carbonate reservoir porosity in Western Canada: Am. Assoc. Petroleum Geologists Bull., v.53, no.3, p.503-512.

Bell, J.M., (1929), The lead-zinc deposits near Pine Point, Great Slave Lake: Trans. Can. Inst. Min. Met., v.32, p.122-139.

______________, (1930), Lead-zinc zones of Great Slave Lake in Lead and zinc deposits of Canada: Geol. Surv. Canada, Econ. Geol. Ser. no.8, p.219-224.

______________, (1931), The genesis of the lead-zinc deposits at Pine Point, Great Slave Lake: Econ. Geol., v.26, no.6, p.611-624.

Bell, Robert, (1902), Mackenzie District: Geol. Surv. Canada, Ann. Rept., 1899, n ser., v.12, pt.A, p.103-110.

Belyea, H.R., and Norris, A.W., (1962), Middle Devonian and older Paleozoic formations of southern District of Mackenzie and adjacent areas: Geol. Surv. Canada, Paper 62-15, p.82.

Bilan, L.J., (1961), North American Tentaculitidae: M. Sc. thesis, Univ. of Alberta, 103pp.

Billings, G.K., Kesler, S.E., and Jackson, S.A., (1969), Relation of zinc-rich formation waters, northern Alberta, to the Pine Point ore deposit: Econ. Geol., v.64, no.4, p.385-391.

Bissell, H.J., and Chilingar, G.V., (1967), Classification of sedimentary carbonate rocks in Carbonate rocks: Origin, Occurrence, and Classification. Elsevier, New York, v.2, p.87-168.

Bonham-Carter, G.F., (1965), A numerical method of classification using qualitative and semi-quantitative data as applied to the facies analysis of limestones: Bull. Can. Petroleum Geol., v.13, p.482-502.

Braun, W.K., (1968), Upper Devonian ostracod faunas of Great Slave Lake and northeastern Alberta, Canada; in Oswald, D.H., ed., Internat. Symposium on the Devonian System, Calgary, Alberta, Sept., 1967, Alberta Soc. Petrol. Geol., v.2, pp.617-652.

Burwash, R.A., (1957), Reconnaissance of subsurface Precambrian of Alberta: Bull. Amer. Assoc. Petroleum Geologists, v.41, no.1, p.91-102.

Calver, Brian, and Farnsworth, D.J.M., (1969), Open-pit dewatering at Pine Point Mines: Can. Inst. Min. Met. Trans., v.72, p.341-347.

Cameron. A.E., (1918), Explorations in the vicinity of Great Slave Lake: Geol. Surv. Canada, Summ. Rept. 1917, pt.C, p.21-28.

______________, (1922), Hay and Buffalo Rivers, Great Slave Lake, and adjacent Country, Northwest Territories: Geol. Surv. Canada, Sum. Rept. 1921, pt.B, p.1-44 (with map 1585).

Cameron, E.M., (1969), Regional geochemical study of the Slave Point carbonates, Western Canada: Can. Jour. Earth Sciences, v.6 no.2, p.247-268.

Campbell, Neil, (1950), The Middle Devonian in the Pine Point area, N.W.T.: Proc. Geol. Assoc. Canada, v.3, p.87-96.

______________, (1957), Stratigraphy and structure of Pine Point Area, N.W.T., in Structural Geology of Canadian Ore Deposits, vol.II, 6th Commonwealth Mining and Met. Congr., Canada, p.161-174.

______________, (1966), The lead-zinc deposits of Pine Point: Trans. Can. Inst. Min. Met., v.69, no.652, p.288-295.

______________, (1967), Tectonics, reefs and stratiform lead-zinc deposits of the Pine Point area, Canada in Genesis of Stratiform Lead-zinc-barite-fluorite deposits, J.S. Brown ed., Econ. Geol., Mon.3, p.59-70.

Camsell, C., (1915), Salt and gypsum deposits of the region between Peace and Slave Rivers, northern Alberta: Geol. Surv. Canada, Summ. Report 1916, p.134-145.

Chilingar, G.V., Bissell, H.J., and Wolf, K.H., (1967), Diagenesis in carbonate rocks, in Diagenesis in sediments-Developments in sedimentology, v.8: Amsterdam, Elsevier Pub. Co., p.179-322.

Chow, T.H., and Patterson, C.C., (1962), The occurrence and significance of lead isotopes in pelagic sediments: Geochim. et Cosmochim. Acta, v.26, p.263-308.

Corneil, B.D., (1968), A paleoecological study of the Ante Creek Reef, Middle to Upper Devonian in age--West Central Alberta: Unpublished M.Sc. thesis, Univ. of Alberta.

Cumming, G.L., and Robertson, D.K., (1969), Isotopic composition of lead from the Pine Point deposit: Econ. Geol., v.64, no.7, p.731-732.

Cumming, L.M., (1967), St. George-Table Head disconformity and zinc mineralization, Western Newfoundland: Bull. Can. Inst. Min. Met., v.61, no.674, p.721-725.

Deffeyes, K.S., Lucia, F.J., and Weyl, P.K., (1965), Dolomitization of Recent and Plio-Pleistocene sediments by marine evaporite waters on Bonaire, Netherlands Antilles, in Dolomitization and limestone diagenesis: a symposium: Soc. Econ. Pal. Min., Spec. Pub. no.13.

Degens, E.T., and Chilingar, G.V., (1967), Diagenesis of subsurface waters, in Diagenesis in sediments-Developments in sedimentology, v.8: Amsterdam, Elsevier Pub. Co., p.477-502.

Doe, B.R., Hedge, C.E., and White, D.E., (1966), Preliminary investigation of the source of lead and strontium in deep geothermal brines underlying the Salton Sea geothermal area: Econ. Geol., v.61, no.3, p.462-483.

Douglas, R.J.W., (1959), Great Slave Lake and Trout River Map Areas, Northwest Territories: Geol. Surv. Canada, Paper 59-11, p.23.

Dumestre, A., and Illing, L.V., (1967), Middle Devonian reefs in Spanish Sahara: in Int. Symposium on the Devonian System, v.2, Alberta Soc. Petroleum Geologists, Calgary, p.331-350.

Dunham, R.J., (1969), Early vadose silt in Townsend Mound (Reef), New Mexico in Depositional Environments in Carbonate Rocks, G.M. Friedman ed., Soc. Econ. Pal. Min., Spec. Pub. 14, p.139-181.

Edie, R.W., (1961), Devonian Limestone reef reservoir, Swan Hills Oil Field, Alberta; Trans. Can. Inst. Min. Met., v.64, p.278-285.

Evans, T.L., (1965), A reconnaissance study of some Western Canadian lead-zinc deposits: Unpublished M.Sc. thesis, Univ. of Alberta, Edmonton.

______________, Campbell, F.A., and Krouse, H.R., (1968), A reconnaissance study of some Western Canadian lead-zinc deposits: Econ. Geol., v.63, no.4, p.349-359.

Fairbridge, R.W., (1966), Diagenetic phases (abstract): Am. Assoc. Petroleum Geologists and Society of Econ. Pal. Min.

______________, (1967a), Phases of diagenesis and authigenesis in Diagenesis in Sediments, G. Laiser, and G.V. Chilingar, eds., Elsevier Amsterdam Developments in Sedimentology, 8, p.19-90.

______________, (1967b), Carbonate rocks and paleoclimatology in the Biochemical history of the planet in Carbonate Rocks: Origin, Occurrence and Classification, G.V. Chilingar, H.J. Bissell, and R.W. Fairbridge eds., Elsevier, New York, p.399-432.

Fischbuch, N.R., (1968), Stratigraphy, Devonian Swan Hills reef complexes of central Alberta: Bull. Can. Petroleum Geol., v.16, no.4, p.444-556.

Fischer, A.G., (1964), Stratigraphic basis of paleoecology, in Approaches to Paleoecology, J. Imbrie and N. Newell eds., J. Wiley and Sons, N.Y., p.32-41.

Folinsbee, R.E., Krouse, R., and Sasaki, A., (1966), Sulphur isotopes and the Pine Point lead-zinc deposits, N.W.T., Canada: a lead-zinc deposit formed from hydrothermal connate brines?: Institution of Min. and Met., Trans. Sect. B, v.76, p.B222, (abstract).

Folk, R.L., (1962), Spectral subdivision of limestone types in Classification of carbonate rocks: Am. Assoc. Petroleum Geologists, Mem.1, p.162-184.

______________, (1965), Recrystallization in ancient limestones, in Dolomitization and Limestone Diagenesis, L.C. Pray and R.C. Murray eds., Soc. Econ. Pal. Min. Spec. Pub. No.13, p.14-48.

Friedman, G.M., (1959), Identification of carbonate minerals by staining methods: Jour. Sed. Pet., v.29, no.1, p.97-197.

Fritz, Peter, (1969), The oxygen and carbon isotopic composition of carbonates from the Pine Point lead-zinc ore deposits: Econ. Geol., v.64, no.7, p.733-742.

Galloway, J.J., (1957), Structure and classification of the stromatoporoidea: Bull. Am. Paleontology, v.37, no.164, p.345-480.

Gebelein, C.D., (1969), Distribution, morphology, and accretion rate of recent subtidal algal stromatolites, Bermuda: Jour. Sed. Pet., v.39, no.1, p.49-69.

Ginsburg, R.N., (1953), Beachrock in south Florida: Jour. Sed. Pet., v.23, p.89-92.

______________, (1957), Early Diagenesis and lithification of shallow water carbonate sediments in south Florida in Regional Aspects of Carbonate Deposition: Soc. Econ. Pal. Min., Spec. Pub. no.5, R.J. LeBlanc and J.G. Breeding, eds., p.80-100.

Goodell, H.G., and Garman, R.K., (1969), Carbonate Geochemistry of Superior Deep Test Well, Andros Island, Bahamas: Am. Assoc. Petroleum Geologists Bull., v.53, no.3, p.513-536.

Gray, F.F. and Kassube, J.R., (1963), Geology and stratigraphy of Clarke Lake gas field, northeastern British Columbia: Am. Assoc. Petroleum Geologists Bull., v.47, no.3, p.467-483.

Grayston, L.D., Sherwin, C.E., and Allen, J.F., (1964), Chapter 5, Middle Devonian, in Geol. Hist. Western Canada; ed. McCrossan and Glaister, Alta. Soc. Petroleum Geologists, Calgary.

Griffin, D.L., (1965), The Devonian Slave Point, Beaverhill Lake, and Muskwa Formations of northeastern British Columbia and adjacent areas: B.C. Dept. Mines and Petroleum Res., Bull. no.50, p.90.

Grootenboer, Johan, and Schwarz, H.P., (1960), Temperature dependent sulphur isotope fractionations between sulfide minerals: Geol. Soc. Am., Atlantic City Annual Meeting, Abstracts, Part 7, p.85.

______________, (1967), The Devonian of northeastern British Columbia in International Symposium on the Devonian System, Calgary, D.H. Oswald, ed., p.803-825.

Gussow, W.C., (1955), Time of migration of oil and gas: Bull. Am. Assoc. Petroleum Geologists, v.39, no.5, p.547-574.

Ham, W.E., ed., (1962), Classification of carbonate rocks: Am. Assoc. Petroleum Geologists, Mem.1.

Hitchon, Brian, (1968), Geochemistry of natural gas in Western Canada in Natural Gases of North America, Mem.19: Am. Assoc. Petroleum Geologists, v.2, p.1995-2025.

Hoagland, A.D., Hill, W.T., and Fulweiler, R.E., (1965), Genesis of the Ordovician zinc deposits in East Tennessee: Econ. Geol., v.60, no.4, p.693-714.

Houbolt, J.J.H.C., (1957), Surface sediments of Persian Gulf near the Quatar Peninsula: Mouton and Co., The Hague, 119p.

Hriskevich, M.E., (1966), Stratigraphy of Middle Devonian and older rocks of Banff Aquitaine Rainbow West 7-32 discovery well, Alberta: Bull. Can. Petrol. Geol., v.14, no.2, p.241-265.

Hurdle, B.E., (1964), The Pine Point Mine: Paper presented at the third National Northern Development Conference, Edmonton, October 21-23, 1964.

Illing, L.V., (1954), Bahamaien calcareous sands: Bull. Amer. Assoc. Petroleum Geologists, v.38, no.1, p.1-95.

______________, (1959), Deposition and diagenesis of some upper Paleozoic carbonate sediments in western Canada: Oilweek, v.10, no.17, p.34-45.

______________, Wells, A.J., and Taylor, J.C.M., (1965), Penecontemporary dolomite in the Persian Gulf in Dolomitization and Limestone Diagenesis: a symposium: Soc. Econ. Pal. Min., Spec. Pub. no.13.

Imbrie, John, and Purdy, E.G., (1962), Classification of modern Bahamian carbonate sediments in Classification of Carbonate Rocks: a symposium: Am. Assoc. Petroleum Geologists, Mem.1.

Irwin, M.L., (1965), General theory of epeiric clear water sedimentation: Am. Assoc. Petroleum Geologists Bull., v.49, p.445-459.

Isbister, A.K., (1855), On the geology of the Hudson's Bay territories, and of portions of the Arctic and northwestern regions of America; with a coloured geological map: Quart. Jour. Geol. Soc. London, v.11, p.497-521.

Jackson, S.A., and Beales, F.W., (1967), An aspect of sedimentary basin evolution: the concentration of Mississippi Valley-type ores during late stages of sediment diagenesis: Bull. Can. Pet. Geol., v.15, no.4, p.383-433.

Jackson, S.A., and Folinsbee, R.E., (1969), The Pine Point lead-zinc deposits, N.W.T., Canada--Introduction and Paleoecology of the Presqu'ile Reef: Econ. Geol., v.64, no.7, p.711-717.

Jamieson, E.R., (1966), The Alexandra reef complex (Frasnian), Hay River area, N.W.T., Canada: Stratigraphy, sedimentology, and paleoecology: Ph.D. thesis, unpublished, Univ. Reading, England.

Jeffs, D.N., (1955), A spectrographic study of elements in ore and host rock at Pine Point Mines Ltd., N.W.T.; Unpublished M.Sc. thesis, Queen's University, Kingston.

Jenik, A.J., and Lerbekmo, J.F., (1968), Facies and geometry of Swan Hills Reef Member of Beaverhill Lake Formation (Upper Devonian), Goose River Field, Alberta, Canada: Bull. Can. Petroleum Geol., v.52, no.4, p.957-981.

Jodry, R.L., (1969), Growth and dolomitization of Silurian Reefs, St. Clair County, Michigan: Am. Assoc. Petroleum Geologists Bull., v.53, no.4, p.957-981.

Kajiwara, Yoshimichi, (1969), Experimental study of sulphur isotope fractionation between coexistent sulfide minerals: Geol. Soc. Am., Atlantic City Annual Meeting, Abstracts, Part 7, p.118.

Kendall, C.G.St.C., and Skipwith, P.A.D'E. (1969), Holocene shallow-water carbonate and evaporite sediments of Khor al Bazam, Abu Dhabi, southwest Persian Gulf: Am. Assoc. Petroleum Geologists Bull., v.53, no.4, p.841-869.

Kinsman, D.J.J., (1964), The Recent carbonate sediments near Halat et Bahrani, Trucial Coast, Persian Gulf: in Developments in Sedimentology, v.1, Deltaic and Shallow Water Marine Deposits: Elsevier Publishing Co., Amsterdam, p.185-192.

_______________, (1969), Modes of formation, sedimentary association, and diagenetic features of shallow-water and supratidal evaporites: Am. Assoc. Petroleum Geologists Bull., v.53, no.4, p.830-840.

Klovan, J.E., (1964), Facies analysis of the Redwater reef complex, Alberta, Canada: Bull. Can. Petroleum Geol., v.12, no.1, p.1-100.

Kramers, J.W., and Lerbekmo, J.F., (1967), Petrology and mineralogy of Watt Mountain Formation, Mitsue-Nipisi area, Alberta: Bull. Can. Petroleum Geol., v.15, no.3, p.346-378.

Langton, J.R., and Chin, G.E., (1968), Rainbow Member facies and related reservoir properties, Rainbow Lake, Alberta: Bull. Can. Petroleum Geol., v.16, no.1, p.104-143.

Laporte, L.F., (1969), Recognition of a transgressive carbonate sequence within an epeiric sea: Helderberg Group (lower Devonian) of New York State, in Depositional environments of carbonate rocks, G.M. Friedman, ed.: Soc. Econ. Pal. Min., Spec. Pub. no.14, p.98-119.

Law, J., (1955a), Rock units of northwestern Alberta: Jour. Alta. Soc. Petroleum Geologists, v.3, no.6, p.81-83.

______________, (1955b), Geology of northwestern Alberta and adjacent areas: Bull. Am. Assoc. Petroleum Geologists, v.39, p.1927-1978.

Leavitt, E.M., (1968), Petrology, paleontology, Carson Creek North reef complex, Alberta: Bull. Can. Petroleum Geol., v.16, no.3, p.298-414.

Leavitt, E.M., and Fishbuch, N.R., (1968), Devonian nomenclatural changes, Swan Hills Area, Alberta, Canada: Bull. Can. Petroleum Geol., v.16, no.3, p.288-297.

Lebedev, L.M., (1967), On contemporary deposits of native lead from the thermal brines of Cheleken: Dokl. Akad. Nauk SSSR., v.174, pp.197-200.

Lecompte, M.J., (1968), Effects of environmental conditions on the skeletons of reef-building organisms and associate faunas in Symposium on Fossils, Ecology and Environments of Carbonate Rocks, May 1968: Sponsored by Depts. of Extension and Geology, Univ. of Alberta and Alta. Soc. Petroleum Geol., p.48-50.

Maxwell, W.G.H., (1968), Atlas of the Great Barrier Reef: Elsevier Pub. Co., New York, 258 p.

______________, and Maiklem, W.R., (1964), Lithofacies analysis, southern part of the Great Barrier Reef: Univ. of Queensland Papers, Dept. of Geology, v.5, no.11, p.21.

McCamis, J.G., and Griffiths, L.S., (1967), Middle Devonian facies relationships, Zama area, Alberta: Bull. Can. Petroleum Geol., v.15, no.4, p.434-467.

McConnell, R.G., (1891), Report on an exploration in the Yukon and Mackenzie Basins, N.W.T.: Geol. Surv. Canada, Ann. Report 1888-1889, v.4, pt.D, p.163.

Murray, J.W., (1966), An oil producing reef-fringed carbonate bank in the Upper Devonian Swan Hills Member, Judy Creek, Alberta: Bull. Can. Petroleum Geol., v.14, no.1, p.1-103.

Murray, R.C., (1960), Origin of porosity in carbonate rocks: Jour. Sed. Pet., v.30, no.1, p.59-84.

______________, (1969), Hydrology of South Bonaire, N.A. -- A rock selective dolomitization model: Jour. Sed. Pet., v.39, no.3, p.1007-1013.

______________, and Pray, L.C., (1965), Dolomitization and limestone diagenesis--an introduction in Dolomitization and Limestone Diagenesis: A Symposium: Soc. Econ. Pal. and Min., Spec. Pub.13.

Nelson, H.F., Brown, C.W., and Brineman, J.H., (1962), Skeletal limestone classification in Classification of Carbonate Rocks: Am. Assoc. Petroleum Geologists, Mem.1, p.224-252.

Newell, N.D., and others, (1953), The Permian Reef Complex of the Guadalupe Mountains Region, Texas and New Mexico -- A study in Paleoecology: W.H. Freeman, San Francisco, p.236.

Ney, C.S., (1957), Monarch and Kicking Horse Mines, in Structural geology of Canadian Ore Deposits; Congress Volume, Inst. Min. Met., p.524.

Noble, E.A., (1962a), Uranium deposits at aquifer junctions: Geol. Soc. America, abstracts.

______________, (1962b), Suggested origin of lead and zinc deposits of the Mississippi Valley type: Geol. Soc. America, abstracts.

Norris, A.W., (1963), Devonian stratigraphy of northeastern Alberta and northwestern Saskatchewan: Geol. Survey Canada, Mem.313, p.168.

______________, (1965), Middle Devonian and older rocks, Great Slave Lake region: Geol. Surv. Canada, Mem.322.

Orme, G.R., and Brown, W.W.M., (1963), Diagenetic fabrics in the Avonian limestones of Derbyshire and North Wales: Proc. Yorkshire Geol. Soc., v.34, p.51-66.

Peck, R.E., and Morales, G.A., (1966), The Devonian and lower Mississippian Charophytes of North America: Micropaleontology, v.12, no.3, p.303-324.

Pfaff, Dieter, (1967), Facies analysis of the Keg River Formation (Middle Devonian in Rainbow B Pool, Alberta: Unpublished M.Sc. thesis, Dept. of Geology, Univ. of Alta., Edmonton.

Playford, P.E., (1967), Devonian reef complexes in the northern Canning Basin, Western Australia: in Internat. Symp. on the Devonian System, Calgary, Alberta Society Petroleum Geologists, v.2, p.351-364.

______________, and Lowry, D.C., (1966), Devonian reef complexes of the Canning Basin, Western Australia: Geol. Surv. Western Australia, Bull. no.118.

Pray, L.C., (1960), Compaction in calcilutites: Geol. Soc. America Bull., v.71, p.1946, (abstract).

______________, and Murray, R.C., editors (1965), Dolomitization and limestone diagenesis: a Symposium: Soc. Econ. Pal. and Min., Spec. Pub.13.

Rice, D.D., (1967), Stratigraphy of the Chinchaga and older Paleozoic formations of the Great Slave Lake area, southern Northwest Territories and northern Alberta; Unpublished M.Sc. thesis, Univ. of Alberta, Edmonton.

Richmond, W.O., (1965), Paleozoic stratigraphy and sedimentation of the Slave Point Formation, southern Northwest Territories and northern Alberta: Unpublished Ph.D. thesis, Stanford University.

Robertson, D.K., (1966), Isotope analysis for lead and sulphur from the Great Slave Lake area: Unpublished M.Sc. thesis, Dept. of Physics, University of Alberta, Edmonton.

Roedder, Edwin, (1968a), Temperature, salinity, and origin of the ore forming fluids at Pine Point, Northwest Territories, Canada, from fluid inclusion studies: Econ. Geol., v.63, no.5, p.439-450.

______________, (1968b), The noncolloidal origin of 'colloform' textures in sphalerite ores: Econ. Geol., v.63, no.5, p.451-471.

Russell, R.D., and Farquhar, R.M., (1960), Lead isotopes in geology: Interscience Pub., New York, p.243.

Rye, R.O., and Czamanske, G.K., (1969), Experimental determination of sphalerite-galena sulphur isotope fractionation and application to the ores at Providencia, Mexico: Geol. Soc. Am., Atlantic City Annual Meeting, Abstracts, p.195-196.

Sangster, D.F., (1968a), Some chemical features of lead-zinc deposits in carbonate rocks: Geol. Surv. Canada, Paper 68-39.

______________, (1968b), Relative sulphur isotope abundances of ancient seas and strata-bound sulphide deposits: Proc. Geol. Assoc. Canada, v.19, p.79-91.

Sasaki, Akira, and Krouse, H.R., (1969), Sulphur isotopes and the Pine Point lead-zinc mineralization: Econ. Geol., v.64, no.7, p.718-730.

Shaw, A.B., (1964), Time in stratigraphy: McGraw-Hill, New York, p.365.

Shearman, D.J., (1963), Demonstration of Recent anhydrite, gypsum, dolomite and halite from the coastal flats of the Arabian shore of the Persian Gulf: Proc. Geol. Soc. London, no.1697, p.63-64.

______________, (1966), Origin of marine evaporites by diagenesis: Inst. Min. Met., Trans., v.74, Sec.B, p.B208-B215; discussion v.76, p.B83-B86.

Shinn, E.A., (1964), Recent dolomite, Sugarloaf Key, in Guidebook for G.S.A. Field Trip No.1, South Florida Carbonate Sediments (compiled by R.N. Ginsburg), p.26-47.

______________, Ginsburg, R.N., and Lloyd, R.M., (1965), Recent supratidal dolomite from Andros Island, Bahamas, in Dolomitization and limestone diagenesis: Soc. Econ. Pal. Min., Spec. Pub. no.13.

Sikabonyi, L.A., and Rodgers, W.J., (1965), Paleozoic tectonics and sedimentation in the northern half of the West Canadian Basin: Jour. Alta. Soc. Petroleum Geologists, v.7, no.9, p.193-216.

Singh, R.N., (1967), An approach to genesis of Pine Point mineralization, N.W.T., Canada: Unpublished M.Sc. thesis, Univ. of Alberta, Edmonton.

Stanton, R.J., Jr., (1966), The solution brecciation process: Geol. Soc. America Bull., v.77, p.843-848.

Tebbutt, G.E., Conley C.D., and Boyd, D.W., (1965), Lithogenesis of a distinctive carbonate rock fabric: Contribution to Geology, Univ. of Wyoming, v.4, no.1, Winter 1965, p.1-13. Reprinted in Carbonate Seminar, Soc. Econ. Pal. Min. Permian Basin Section, 11th Ann. Mtg., Midland Texas, April 1966.

Tyrrell, W.W., (1969), Criteria useful in interpreting environments of unlike but time-equivalent carbonate units (Tansill-Capital-Lamar), Capitan Reef complex, West Texas and New Mexico in Friedman, G.M., ed., Depositional environments of carbonate rocks: Soc. Econ. Pal. Min., Spec. Pub., no.14, pp80-97.

Uyeno, T.T., (1967), Condont zonations, Waterways Formation (Upper Devonian), Northeastern and Central Alberta; Geol. Surv. Canada, Paper 67-30.

Vasquez, Julio, (1968), Fluid inclusion studies, Pine Point ores: Unpublished M.Sc. thesis, Queen's Univ., Kingston.

Warren, P.S., and Stelck, C.R., (1956), Reference fossils of Canada, Part I; Devonian faunas of Western Canada: Geol. Assoc. Canada, Spec. Paper no.1.

Warren, P.S., and Stelck, C.R., (1962), Western Canadian Givetian: Jour. Alta. Soc. Petroleum Geologists, v.10, no.6, p.273-291.

Weeks, L.G., (1948), Principles of basin development, sedimentation and oil occurrence: Standard Oil Development Company, New York, p.230.

Weyl, P.K., (1960), Porosity through dolomitization: Conservation-of-mass requirements: Jour. Sed. Pet., v.30, no.1, p.85-90.

White, D.E., (1968), Environments of generation of some base-metal ore deposits: Econ. Geol., v.63, no.4, p.301-335.

Williams, H.H., (1967), Some aspects of ion exchange in shales: Unpub. M.S. thesis, Univ. of Calgary, p.182.

Wolf, K.H., (1965a), Petrogenesis and paleoenvironment of Devonian algal limestones of New South Wales: Sedimentology, v.4, p.113-178.

_____________, (1965b), 'Grain dimunution' of algal colonies of micrite: Jour. Sed. Petrol., v.35, p.420-427.

PLATE 1

Dolomite fabrics, Presqu'ile Formation (except as noted).

In this and all subsequent plates bedding is normal to the long axis of cores except as noted. All samples are polished surfaces of slabbed core or hand specimen except as noted.

1:1, 1:2, 1:3. Coarsely crystalline dolomite showing clusters of dolomite crystals with dark centres, some with concentric banding. Origin of this rock type is an enigma (see Fig.1:4). In some cases the dark centres are due to finely disseminated iron and lead sulphide as determined by electron microprobe. All samples from O42 pit walls. Scale in cm.

1:4. Polished limestone slab from a lens in O42 pit which is enveloped by coarsely crystalline dolomite. Incipient dolomitization of this biopelsparite has occurred at scattered centres. Increased porosity in these centres allowed dark polishing abrasive to penetrate this specimen giving it a "polka-dot" appearance. Scale in cm.

1:5, 1:6. Polished slabs showing poorly preserved Amphiporids in vertical and horizontal section. Bedding plane section (Fig.1:6) reveals the elongate nature of the fossils. Specimen from O42 pit wall. Scale in cm.

1:7 Dolomite with vague outlines suggestive of fossils. This rock may have originated from an Amphipora-rich limestone but this cannot be determined. Scale in cm. Core 1386-400', bedding vertical.

1:8 Another variation of the coarsely crystalline dolomite. The vague shapes in the rock are suggestive of crinoid ossicles but no proof is obtainable. Abundant white sparry dolomite has replaced all of the matrix. Scale in cm. Core 1386-340'.

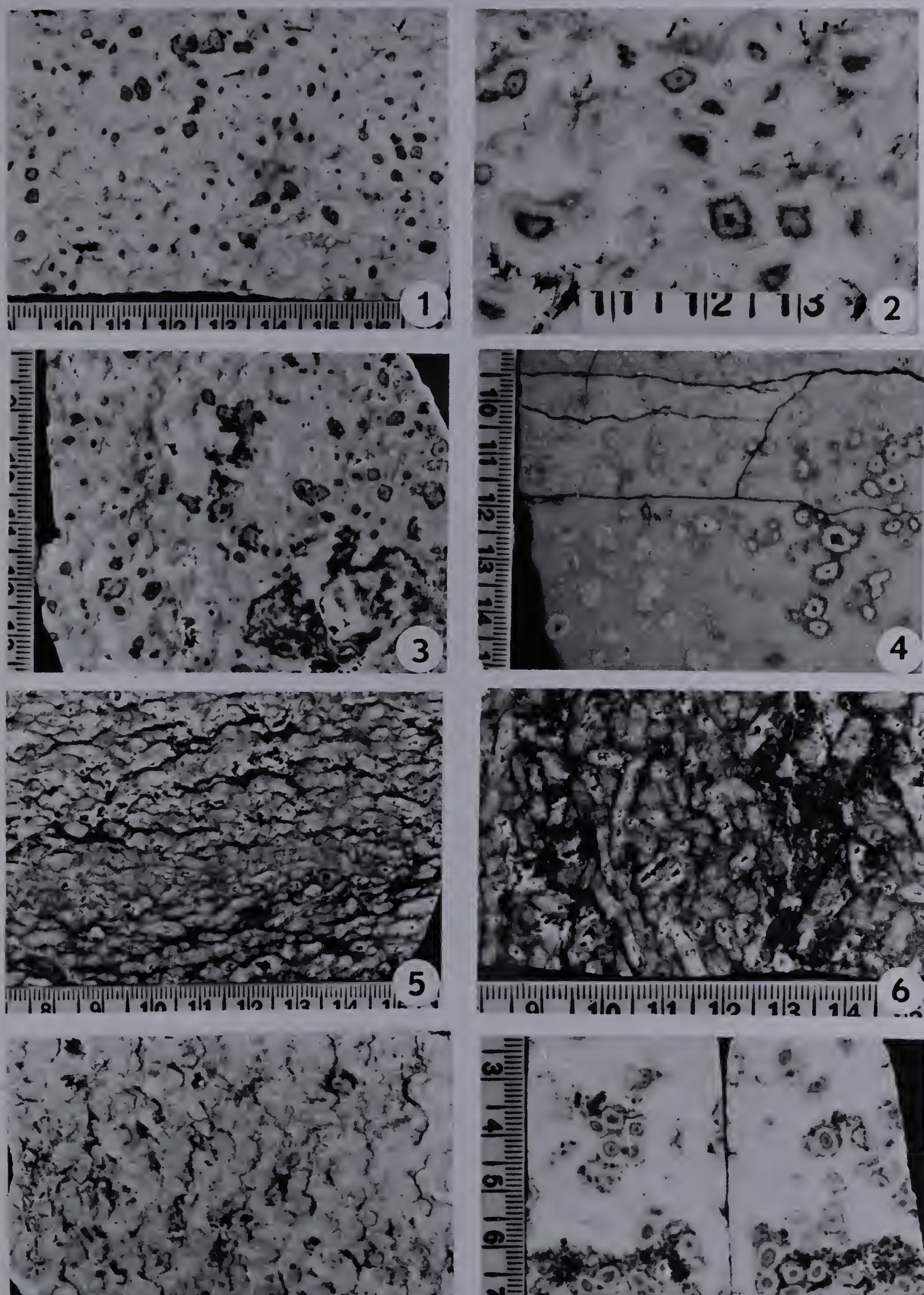


PLATE I.

PLATE 2

LIMESTONE AND DOLOMITE FABRICS

2:1 Presqu'ile Formation. Biogenic texture in medium crystalline dolomite with outlines of fragments emphasized by bitumen. Large fragments appear to be stromatoporoids and gravel-sized material is probably Stachyodes or Amphipora. Specimen from N32 pit wall about 20 feet from surface. Scale in inches. Bedding horizontal.

2:2 Biogenic dolomite from the Pine Point Formation in which fossils have been replaced by dolomite and anhydrite and their classification is impossible to any degree of certainty. Scale in inches. Core Conwest 310-402 @ 333'.

2:3 and 2:4. Limestones from fore-reef detritus of the Sulphur Point Formation for comparison to Figures 2:1 and 2:2. Biogenic textures similar to these shown in limestone are common in the dolomites where the fossils cannot be identified even to phylum. Scale in cm. Bedding vertical.

2:5 and 2:6. Two specimens with coarse bioclastic fragments. Fig.2:6 shows biosparrudite in which fragments are identifiable as corals, Stachyodes, Amphipora and algae but in Fig. 2:5 none of the fragments except a gastropod is recognizable. Fig.2:5 scale in inches, from N32 pit. Fig.2:6 scale in cm.

2:7 and 2:8. Pine Point Formation. Bioclastic brown dolomite. Dolomites with fine-grained bioclastic relicts. Both specimens exhibit recognizable grains even though completely dolomitized. White material in Fig.2:7 is gypsum; scale in cm.; in Fig.2:8 it is calcite with a bitumen rim. Native sulphur is often found with this type of calcite.

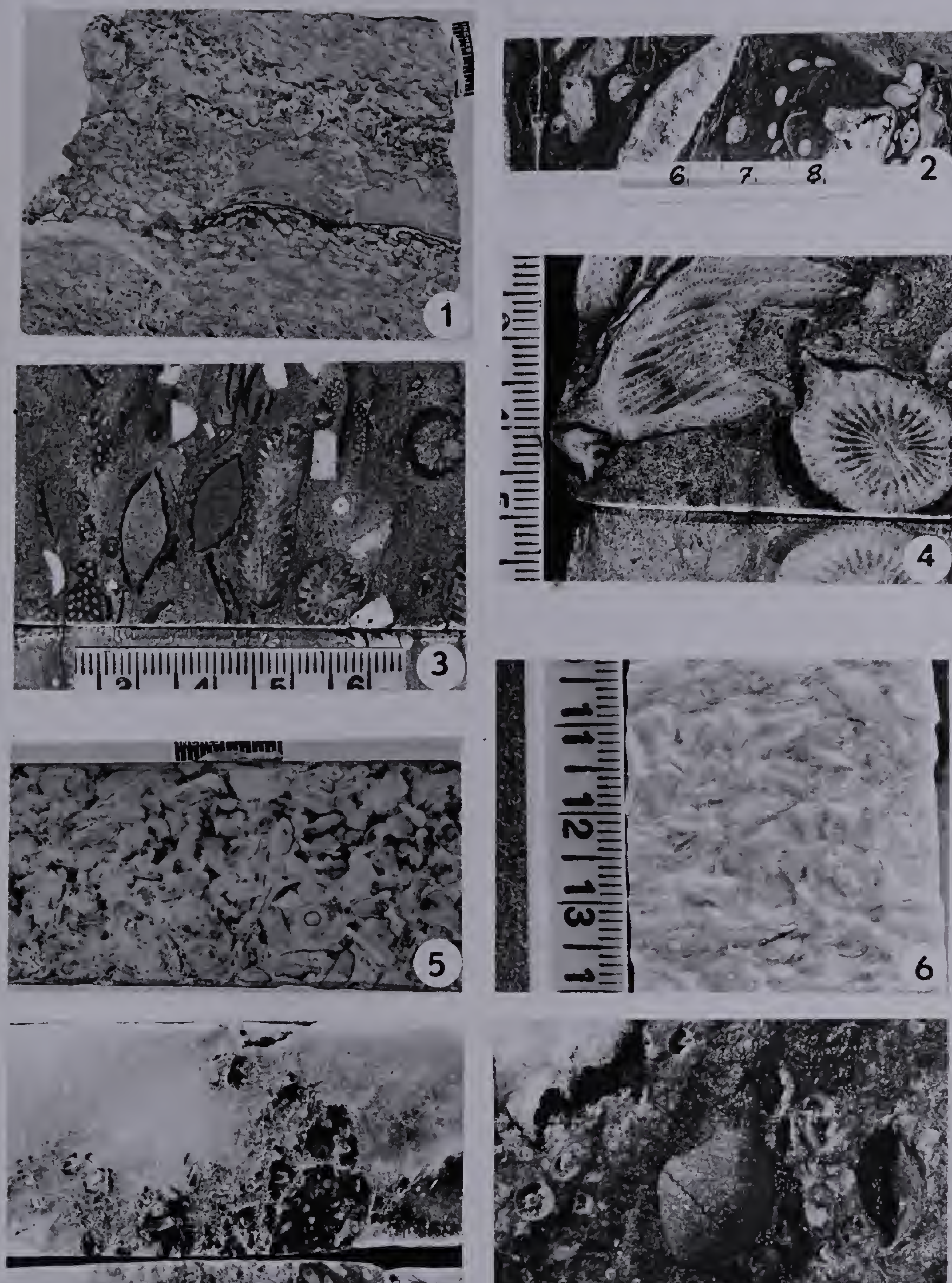


PLATE II.

PLATE 3

DOLOMITE FABRICS (EXCEPT AS NOTED)

3:1 Pine Point Formation. Bioclastic brown dolomite with excellent intercrystalline porosity. Scale in inches. Core 923-530'.

3:2 Coarsely crystalline dolomite facies. Dolomite composed of almost completely uncemented dolomite rhombs. Some of this lithology also occurs in the Pine Point and lower Slave Point Formations. Scale in cm.

3:3 Cohesive brown dolomite facies. D3 marker bed. Bedded breccia zone composed of finely crystalline grey to brown fragments in a white dolomite matrix. Scale in cm.

3:4 Brecciated friable brown dolomite fragments (1) rimmed with white dolomite (2) that has been re-brecciated and veined with calcite (3). Calcite in incomplete core view is stained with Alizarin red S. Scale in cm.

3:5 Pseudo-breccia or latticework zone from O42 pit showing bands of white sparry dolomite surrounding remnants of buff and brown finer grained dolomite. The material looks brecciated though it may have suffered no tectonism or collapse. Sample from the area shown in Fig.3:6.

3:6 Latticework dolomite. View of O42 pit wall showing bedded zone of latticework which wedges off within a few hundred feet between other dolomite beds. The lattice is composed of brown sucrosic dolomite cores surrounded by coarse encrusting white dolomite with large rectangular vugs arranged in tiers. Minor offset on brown remnant beds is is common. Hammer for scale has 18-inch handle.

3:7. Boxwork dolomite. Specimen from wall of N32 pit showing very abundant isolated vugs with very thin walls. Scale in cm.

3:8 Boxwork dolomite. Close-up of polished slab of dolomite shown in Fig.3:7 showing detail of vug walls. This rock originated by the preferential solution of fragments (dolomite, limestone and possibly evaporites) from between healed fractures, creating breccia-moldic porosity. Scale in mm.

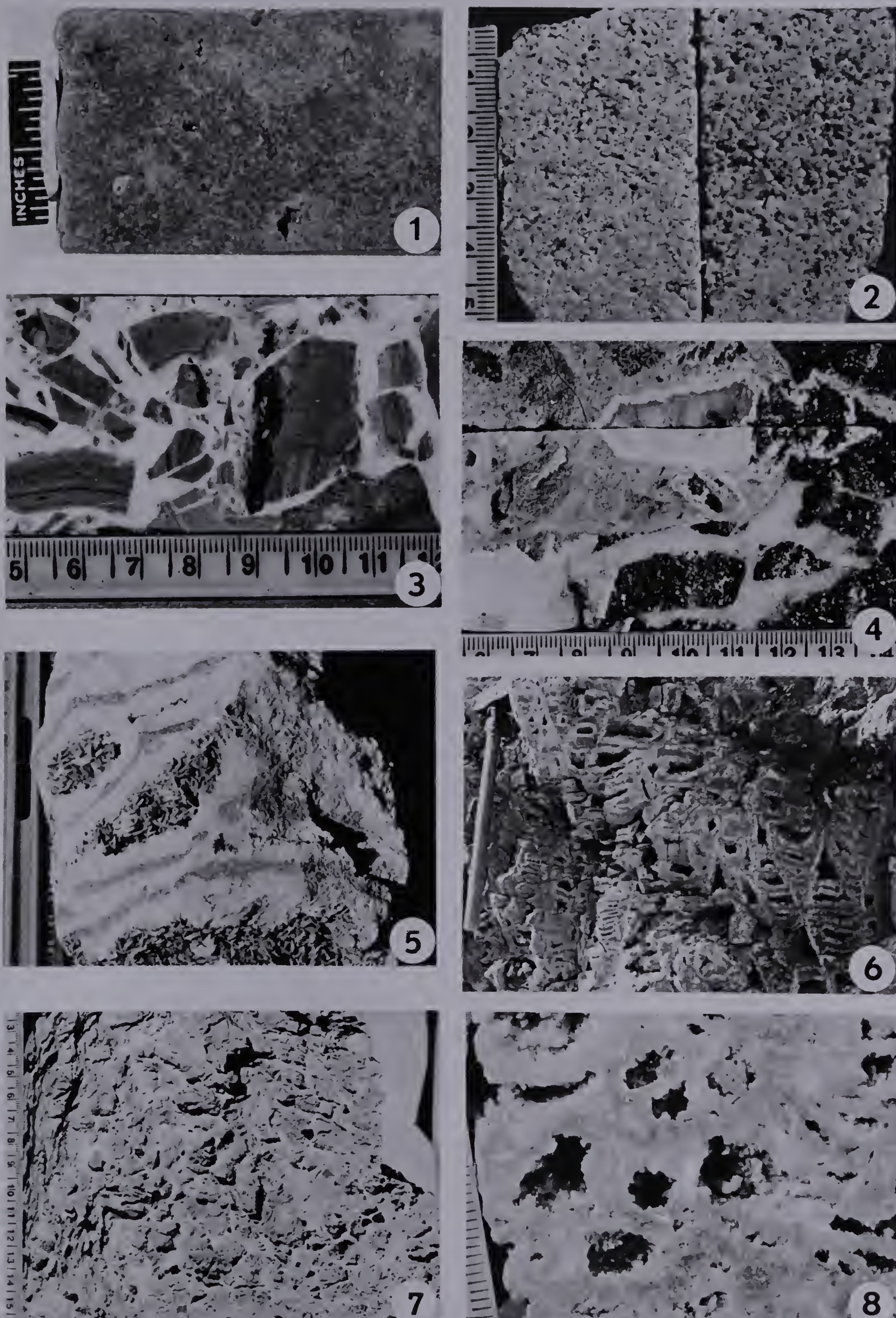


PLATE III.

PLATE 4

DOLOMITE FABRICS

4:1. Coarsely crystalline dolomite facies -- laminated vuggy dolomite, from N42 pit wall. White crystalline dolomite has invaded the rock parallel to bedding giving a banded appearance. Hammer handle for scale.

4:2. Laminated brown limestone and mottled dolomite facies. Laminated dolomitic limestone from the Slave Point Formation. This material may have originated as an algal mat deposit but no algal filaments are recognized. Where more dolomitized, (e.g. Fig.5:8) it is more obscure and the term laminated is applied with little genetic implication. Scale in mm. Core 1351-188'.

4:3. Laminated vuggy dolomite in the coarsely crystalline dolomite facies, from O42 pit walls. Section shown on left; bedding plane surface cleaved along vugs shown on right. The rock is composed of coarsely crystalline dolomite but laminations are preserved. This texture may have originated from limestone similar to that shown in Fig.4:2 but this cannot be proven. Scale in inches.

4:4 Laminated brown limestone and mottled dolomite facies. Mottled dolomite. Mottling of many types occurs within the various fine-grained dense dolomites. It may persist into recrystallized rocks. Scale in inches.

4:5, 4:6. Coarsely crystalline dolomite facies. Presqu'ile Formation. Two core specimens in which vein material predominates and matrix material is insufficient for description. In Fig.4:5 at least four phases of coarse dolomite are visible. Fig.4:6 shows that co-precipitation of dolomite and gypsum/anhydrite occurred even in veins and fracture fillings. In some cases it is now pseudomorphed by calcite but in many cases is preserved as gypsum or anhydrite. Scale in cm.

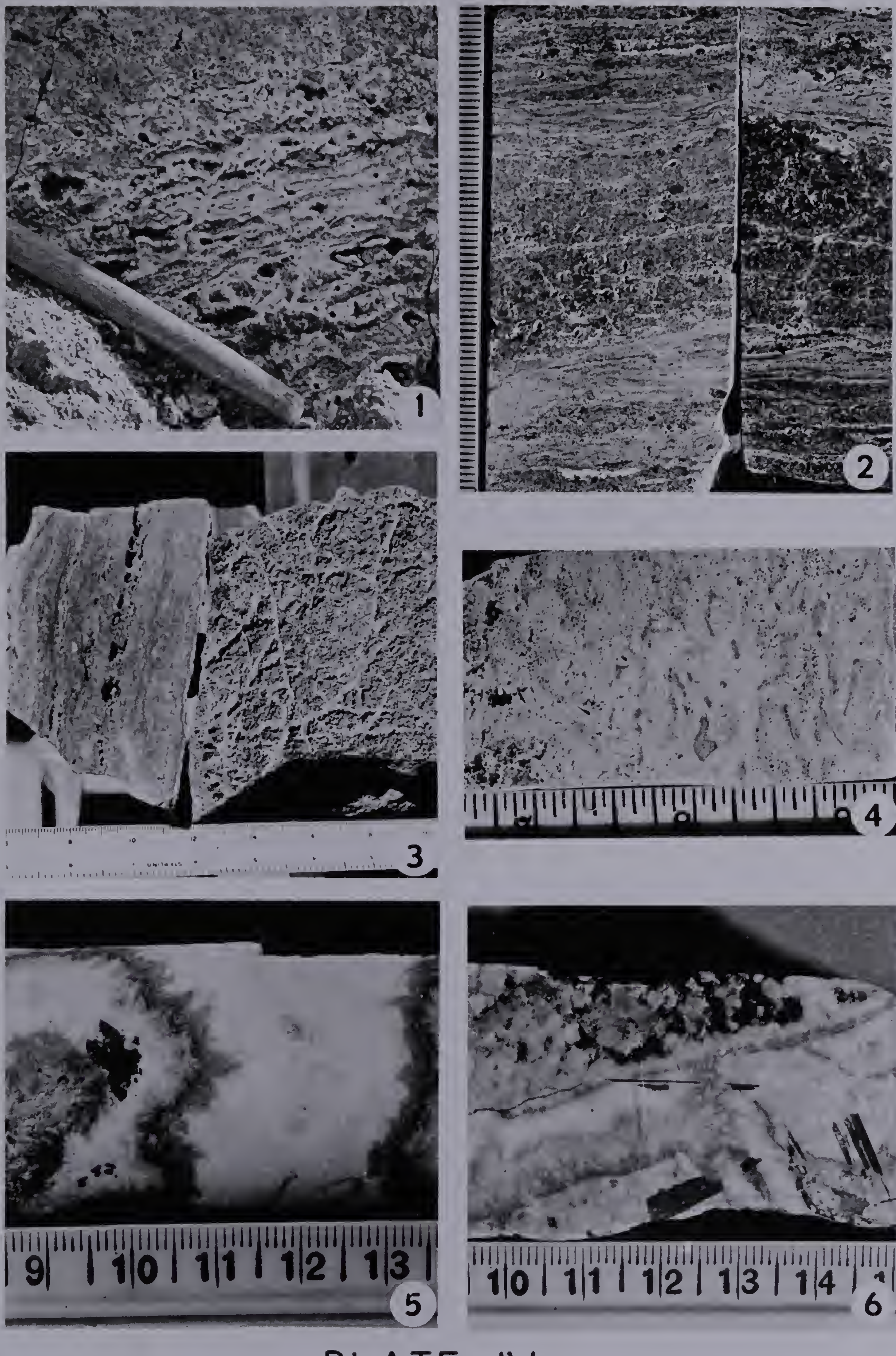


PLATE IV.

PLATE 5

PINE POINT FORMATION

5:1 Bituminous limestone/dolomite facies. Limestone (biomicrite) showing crinoids, brachiopod debris in an argillaceous, fine-grained, poorly laminated matrix. Scale in mm.

5:2 Bituminous limestone/dolomite facies. Dolomite with scattered brachiopods and crinoids and undulose argillaceous-bituminous laminae. Entire brachiopods, filled with calcite, sphalerite, and galena crystals.

5:3 Coelenterate biolithite and rubble facies. Dolomite with platy and dendroid stromatoporoids, and colonial corals, in a fine-bioclastic matrix. The whole rock is now altered to finely crystalline dolomite and is fractured and veined and has all porosity choked with fibrous gypsum and anhydrite. Scale in inches. Core from Patricia Silver 66-2 @ 650'.

5:4 Coelenterate biolithite and rubble facies. Detritus composed of subspherical and platy stromatoporoids, <u>Amphipora</u>? and <u>Thamnopora</u> in an argillaceous-bituminous dolomite matrix. Fossils have been replaced by anhydrite and coarsely crystalline dolomite. Some of the anhydrite has been leached, leaving vuggy porosity. Scale in inches. Core from Conwest 310-402 @ 333'.

5:5 Coelenterate biolithite and rubble facies. Large solitary corals in growth position surrounded by a colonial coral and fine-grained bioclastic debris. This material presumably developed on the fore-reef slope adjacent to the reef. Scale in inches. Core from Conwest 309-502 @ 341'.

5:6 Coelenterate biolithite and rubble facies. Medium crystalline dolomite with <u>Thamnopora</u> and some <u>Amphipora</u>? all set in an argillaceous laminated matrix containing minor fine bioclastic debris. Scale in 1/16 in. div. Core 1351-350'.

5:7 Coelenterate biolithite and rubble facies. Large horn corals and <u>Thamnopora</u> set in an argillaceous biosparite matrix. Scale in mm. Core 1351-355'.

5:8 Laminated brown dolomite. Medium crystalline dolomite with irregular argillaceous banding. Scale in 1/16 inch divisions.

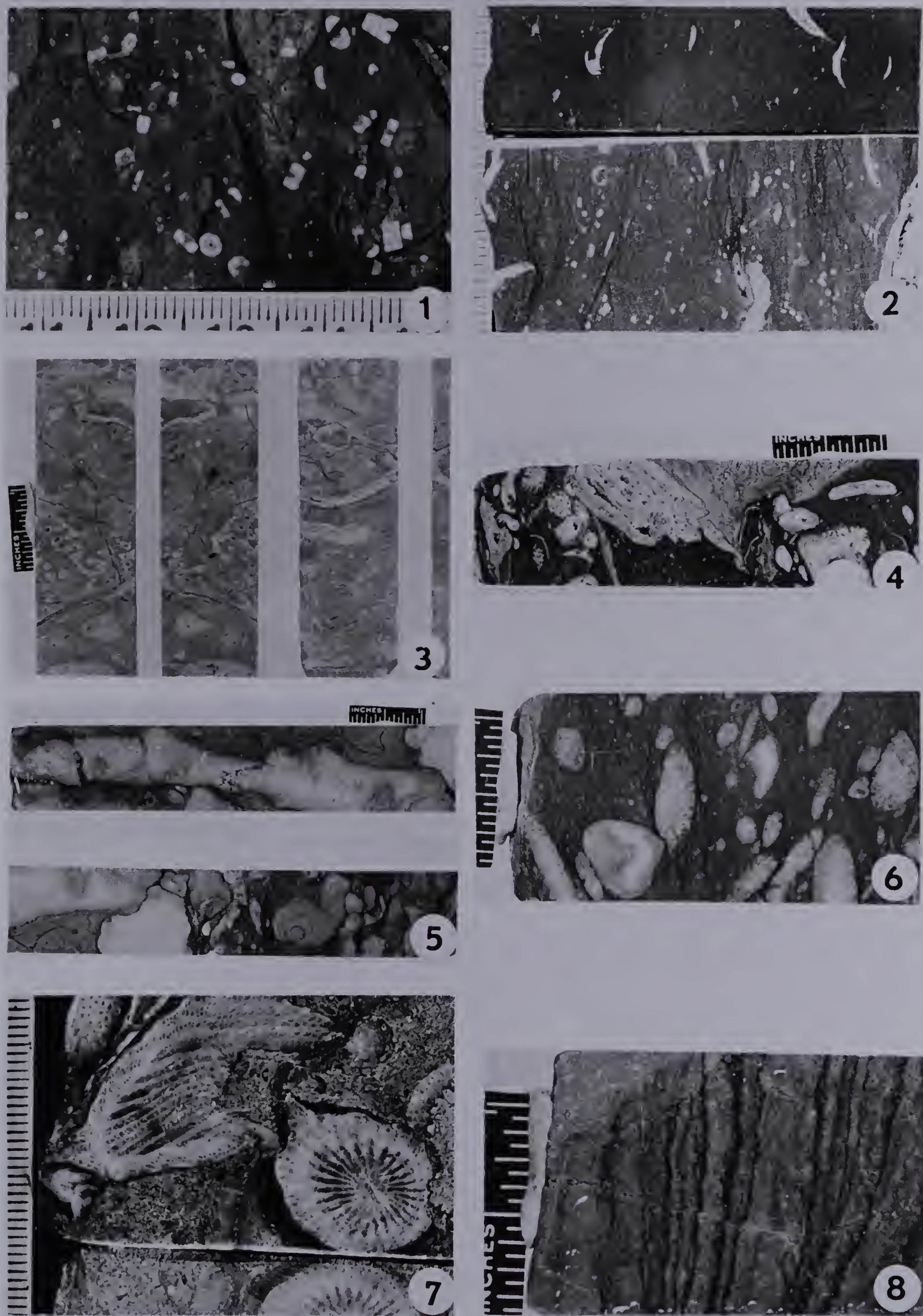


PLATE V.

PLATE 6

PINE POINT FORMATION

6:1. Laminated brown dolomite. Polished slab from X15 pit near top of Pine Point Formation showing well-developed irregular laminations and bedded vuggy porosity. Considerable crystalline galena and sphalerite lines vugs as the specimen was taken very close to an orebody.

6:2. Brecciated laminated brown dolomite. Such brecciation is due to solution or reworking before burial. Scale in inches. Core 923-460'.

6:3 and 6:4. Laminated brown dolomite. Laminated and mottled finely crystalline dolomites with large clusters of coarsely crystalline milky white calcite and minor sulphur. Laminae tend to bend around clumps. It is thought that this rock originated as a fine carbonate mud in which nodules of gypsum and anhydrite grew during early diagenesis. The sulphates were later replaced by calcite. Scale in inches.

6:5. Bioclastic brown dolomite. The fine to coarse bioclastic debris is composed in part of stromatoporoid fragments and Amphipora grains. The remainder of the fragments cannot be identified but are presumed to be bioclastic in nature. The entire specimen is dolomitized to finely crystalline brown dolomite. Scale in inches.

6:6. Non-laminated brown limestone and dolomite facies. Finely crystalline dolomite with well-developed argillaceous bituminous laminae. Thamnopora fragments and minor Amphipora? material has presumably been washed in, since they lie parallel to the bedding. Scale in inches.

6:7. Bioclastic brown dolomite. Finely crystalline light brown dolomite with large brachiopods and brachiopod debris partly infilled with white sparry calcite and partly filled with internal sediment. Scale in inches. Core 1357-146'.

6:8. Bioclastic brown dolomite. Medium crystalline bituminous dolomite with packed remnants of Amphipora which have been diminished in thickness by pressure solution to appear almost as crinkly laminations. The matrix has been largely recrystallized and/or dissolved and the crystal size approaches that typical of the coarsely crystalline dolomite facies. Specimen is from near the contact of the Pine Point and Presqu'ile Formations. Scale in inches.

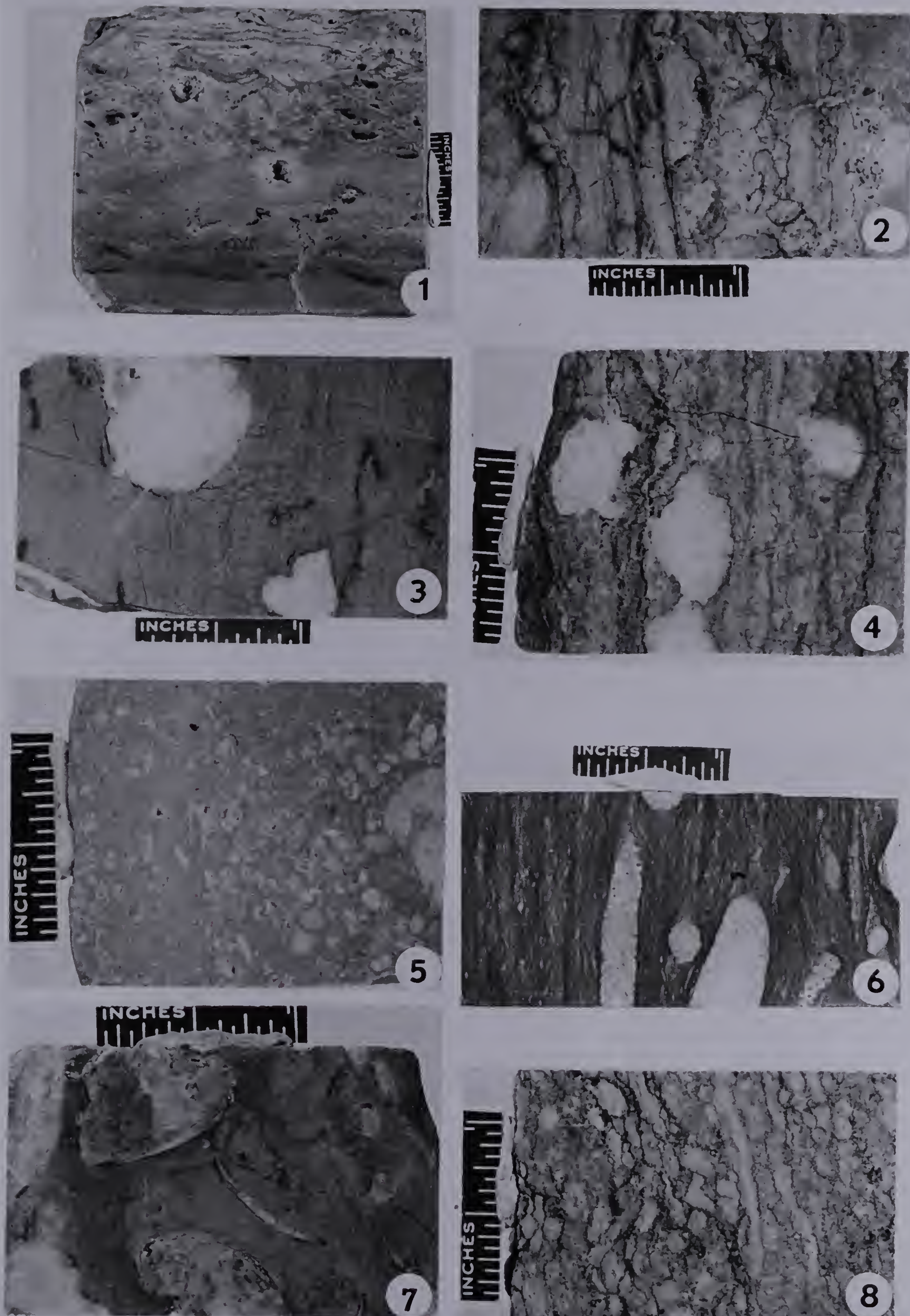

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PLATE VI.

PLATE 7

PRESQU'ILE AND SULPHUR POINT FORMATIONS

7:1. Sulphur Point Fm. Coelenterate biolithite and rubble facies. Large tabular stromatoporoids and minor *Amphipora* or *Thamnopora* fragments in an argillaceous biosparite matrix. Scale in inches. Hole 1343-40'.

7:2. Sulphur Point Fm. Coelenterate biolithite and rubble facies. Fossils have been replaced by anhydrite and dolomite. *Thamnopora*, brachiopods and subspherical stromatoporoids are set in an argillaceous, bituminous, biosparite matrix. Scale in inches. Hole 1343-50' approximately.

7:3. Presqu'ile Formation. Dolomite with anhydrite pseudomorphs. An intimate mixture of calcite and dolomite (with the calcite (darker) pseudomorphic after anhydrite) forms this rock. Scale in inches. Core 136-80'.

7:4. Presqu'ile Formation. Dolomite with anhydrite pseudomorphs. Coarsely crystalline dolomite and anhydrite (or calcite pseudomorphs) are commonly intergrown indicating the presence of sulphates during dolomitization and simultaneous deposition of dolomite and anhydrite. Scale in mm.

7:5. Whole fossil biosparite-pelsparite. Sulphur Point Formation. Large brachiopod shells set in a matrix of fine-grained biosparite. Scale in inches. Core 221-88'.

7:6. Sulphur Point Formation. Biosparrudite with crowded rounded fragments of *Amphipora*, corals and algae, with some pellets. Highly etched with HCl. Scale in cm.

7:7. Sulphur Point Formation. Whole-fossil biosparite-pelsparite. Biopelsparite with coral and *Amphipora* fragments with encrusting stromatoporoids. Scale in inches.

7:8. Sulphur Point Formation. Biosparrudite with fragments of brachiopods, *Amphipora*, and algae. Both white and clear sparry calcite cement occur. Scale in inches. Core 290-114'.

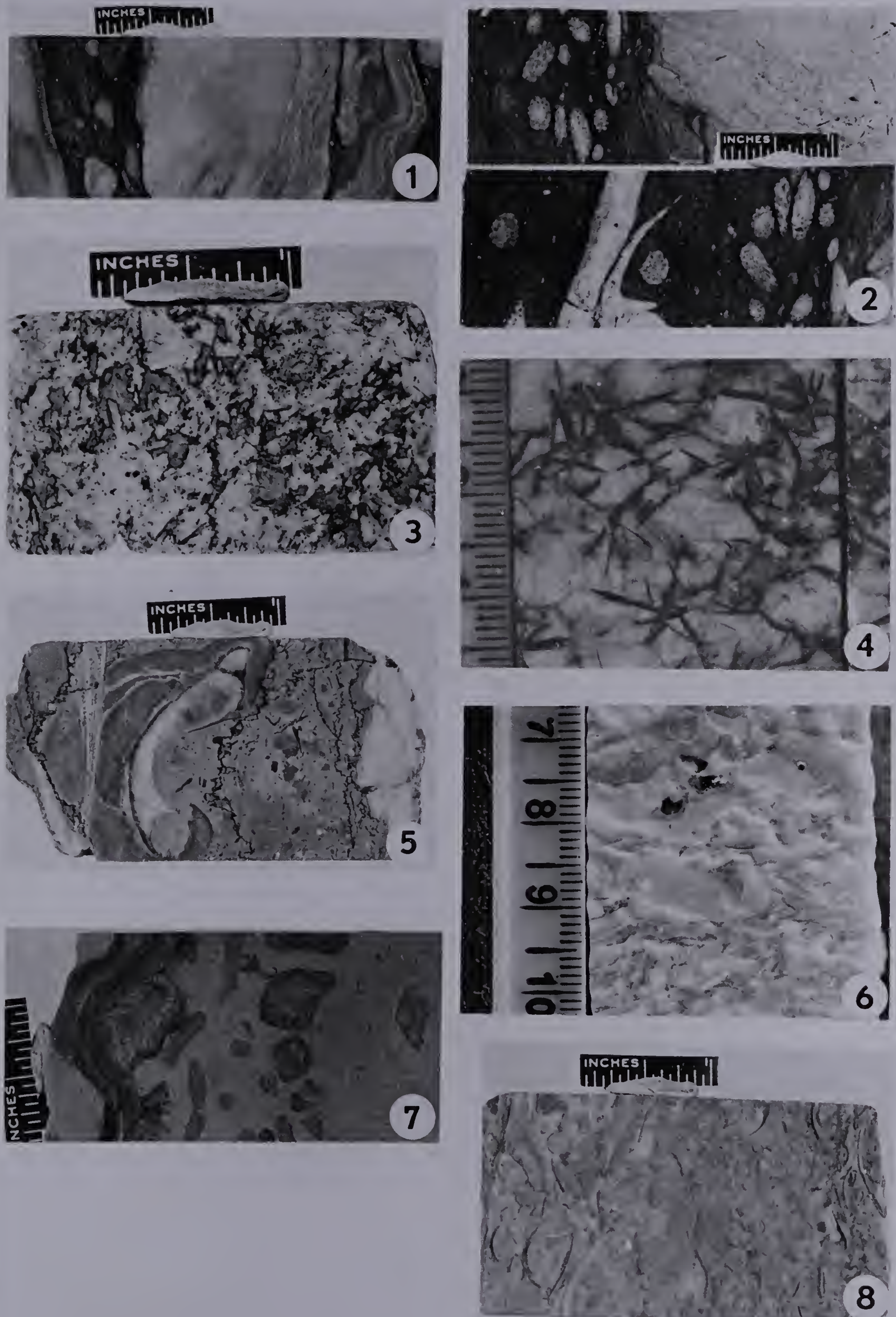


PLATE VII.

PLATE 8

SULPHUR POINT AND SLAVE POINT FORMATIONS

8:1. Sulphur Point Formation. Biosparite in which fossil debris and micritic algal (?) fragments are tightly cemented by bitumen and sparry calcite. Scale in inches.

8:2. Sulphur Point Formation. Pelsparite with calcite and bitumen-filled rosettes pseudomorphous after anhydrite (and celestite?). This is interpreted to be a restricted lagoonal deposit.

8:3 and 8:4. Gypsiferous limestone/dolomite facies. This lithology is encountered in both the Sulphur Point and lower Slave Point Formation. Fig.8:3 shows nodular gypsum with interstitial fine-grained light brown dolomite cut by gypsum-filled fractures. Fig.8:4 consists mainly of finely interlaminated gypsum (clear, dark in photo) and fine-grained light brown dolomite (light-coloured in the photo). Scale for 8:3 in cm., for 8:4 in inches. Core 1350-254'.

8:5 Sulphur Point Formation. White biosparite-pelsparite. Biopelsparite with abundant fine bioclastic fragments, much pelleted mud, and occasional Amphipora all tightly cemented with sparry calcite. Scale in cm/mm.

8:6 Slave Point Formation. Bedded brown fine-grained limestone facies. Intramicrite from the uppermost Slave Point limestone showing intraclasts most of which have oncolitic coatings. Scale in inches.

8:7. Slave Point Formation. Bedded brown fine-grained limestone facies. Subspherical stromatoporoids from the Slave Point limestone. Bedding vertical. Scale in cm.

8:8. Slave Point Formation. Bedded brown fine-grained limestone facies. Laminated micrite. Regular bituminous laminae possibly indicate deposition in fairly quiet deeper water with possibly some algal trapping of sediment. Scale in cm. Core 1386-146'.

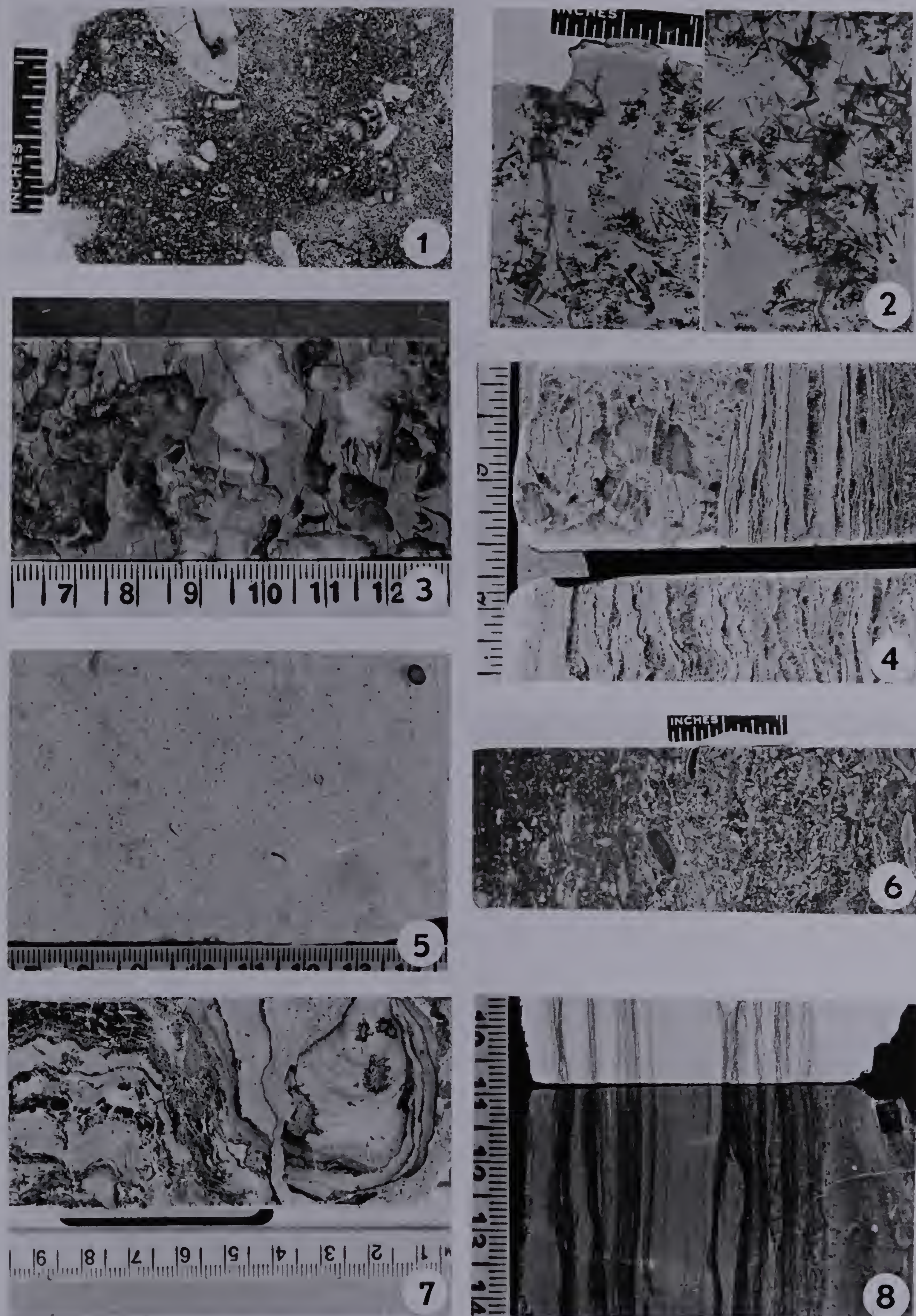


PLATE VIII.

PLATE 9

AMCO MARKER AND DOLOMITIZATION (GENERAL)

9:1. Amco Marker. Argillaceous dolomitic limestone facies. Sample from the top or bottom brachiopod-crinoid zone showing abundant articulated shells and fragments in a fine-grained dolomitic argillaceous micrite. Scale in cm.

9:2 and 9:3. Sulphur Point Formation. White biosparite-pelsparite facies with clusters of sparry calcite cement in a pelmicrite matrix. Fig.9:3 displays dolomitization of this rock type with indiscriminate replacement of sparry cement and pelleted matrix. In Fig.9:3 the darker core has been stained with Alizarin Red S. and dolomite shows up as white reticulate lines. Scale in cm/mm. Core 290-80' (approx.) (both samples).

9:4 Sulphur Point Formation. White biosparite-pelsparite facies. Biosparrudite composed of thick-shelled brachiopods with minor green shale in the matrix. Incipient dolomitization of matrix and the margins of fragments has begun but no further gradation to dolomite is observed in the core. A sharp transition from material in this condition to 100 percent coarsely crystalline dolomite generally occurs. Scale in cm. Core 1362-289'.

9:5 Sulphur Point Formation. Incipient dolomitization of white biosparite-pelsparite facies. Very coarsely crystalline dolomite has replaced fine-grained biopelsparite along fractures etc. but has developed little porosity. Specimen stained with Alizarin Red S., dolomite is white. Scale in cm.

9:6 Sulphur Point Formation. Partial dolomitization of similar material to that shown in the previous photo but less dolomite has formed and considerable porosity has developed. Scale in cm. Core 143-288'.

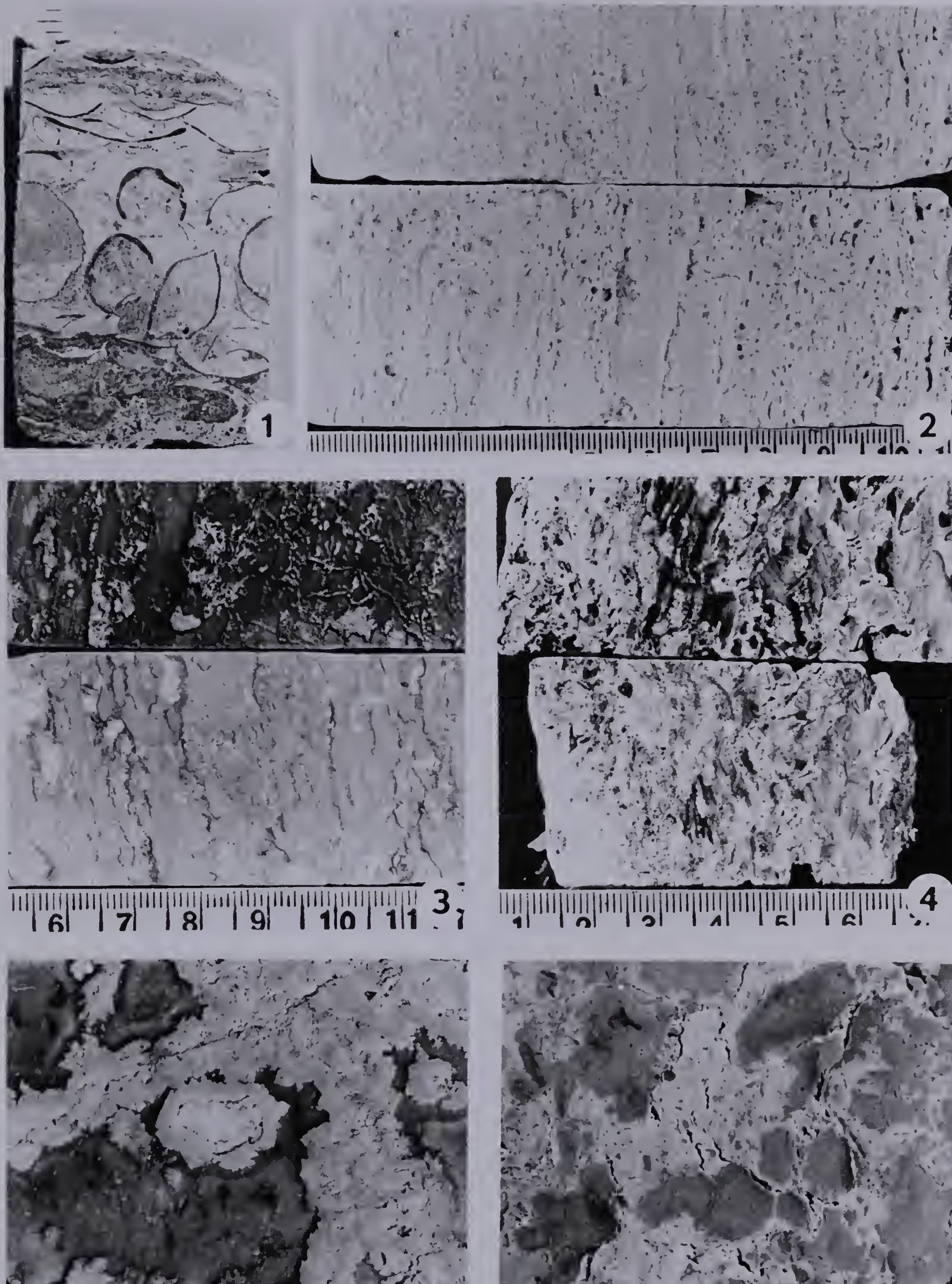


PLATE IX.

APPENDIX A

SUMMARY OF ECONOMIC DEVELOPMENTS AT PINE POINT 1898-1970

1800's	Surface lead-zinc deposits were known to the local Indians prior to 1897 (Baragar, 1964, p.18).
1898	The first claims in the area were staked by prospectors travelling through to the Yukon gold fields (Hurdle, 1964).
1899	Examination by Robert Bell of the Geological Survey of Canada indicated that the ores contained only low amounts of precious metals (Baragar, 1964, p.18).
1914	G.G. Gibbons, Vancouver, staked claims for the Huronian Belt Co. of London, England. Claims were dropped at the onset of the First World War. Claims were also staked by Paine, Weber and Co., H.L. Smyth, and J. MacIntosh Bell.
1921	C.B. Dawson examined claims in the area for a Boston syndicate.
1928	Atlas Exploration Co. undertook a joint exploration program with the Boston syndicate.
1929 & 1930	Atlas Exploration Co., a Boston syndicate, Consolidated Mining and Smelting Co. (Cominco), and Ventures Ltd. formed a new company known as Northern Lead Zinc Co. Ltd. Churn drilling and sinking of a 94-foot shaft were carried out. Reserves of 500,000 tons of lead-zinc ore were delineated.
1930-1947	Little exploration was carried out in the area during this period.
1947	Northern Lead Zinc Co. Ltd., Cominco Ltd., and Ventures Ltd., were granted a 500 square mile concession near Pine

Point. Detailed exploration was begun.

1948-1953 Diamond drilling was carried out over a large area (192,000 feet in over 900 holes).

1950 At the termination of the concession agreement a block of 1099 claims was staked. Ventures assigned its interest to Cominco Ltd.

1951 A new company, Pine Point Mines Ltd., was formed to hold the property of Cominco and Northern Lead Zinc. Cominco eventually acquired a 78% interest in Pine Point Mines (currently 69%).

1961 A decision was reached by the Canadian Government to build a railroad to Great Slave Lake from Grimshaw, Alberta. Pine Point Mines Ltd. undertook to bring its property into production by Dec. 31, 1966. An agreement was signed to ship all ores and concentrates by rail for 10 years at a minimum rate of 215,000 tons of concentrates per year. Estimated reserves at that time were 5 million tons grading 4% lead and 7% zinc, with indications that much more ore could be blocked out.

1965 Shipments of high grade ore (over 50% lead plus zinc) from open pits at Pine Point valued at $26,482,000 resulted in a net profit of $22,132,000. New geophysical techniques (induced polarization) and drilling had increased ore reserves to 21.5 m.t. averaging 4% lead, 7.2% zinc with indications of more ore being present. The Pine Point mill started with a rated capacity of 5,000 t.p.d. Pyramid Mines Ltd. discovered orebodies

with reserves of 11.2 million tons averaging 2.5% lead, 8% zinc. Thousands of new claims were staked by many operators covering an area 20 by 30 miles.

1966 Pine Point Mines Ltd. acquired the Pyramid properties in exchange for 526,400 Pine Point Mines Ltd. shares. Cominco holdings then represented 69% of the issued stock. Pine Point Mines reserves (including Pyramid orebodies) were placed at 37.8 m.t. averaging 2.9% lead, 6.8% zinc. Conwest Explorations Ltd. and Newconex Explorations outlined 1.25 m.t. of ore averaging 13% combined lead-zinc. Coronet Mines Ltd. outlined reserves in the order of 1.1 m.t. of 13.1% combined lead-zinc.

1967 Pine Point Mines Ltd. started expansion of its mill to reach a rated capacity of 8,000 tons per day to handle ore from the Pyramid property. Production from the Pyramid property (Sphinx Mine) commenced late in 1968, increasing the rate to over 9,000 tons per day.

1968 Exploration was carried out by several mining companies including Pine Point Mines Ltd. and Coronet Mines Ltd. Yellowknife Base Metals Ltd. indicated ore on one property. Reserves of Pine Point Mines Ltd. at the end of 1968 are listed as 39.3 million tons grading 2.6% lead, 6.8% zinc. Table 3 of text summarizes production, earnings and reserves for Pine Point Mines Ltd. from 1964-1969.

1969 Drilling to further delineate Coronet ore commenced in January, 1969. Yellowknife Base Metals Ltd. announced reserves of 338,000 tons grading 6% zinc, 1.74% lead,

with drilling continuing.

1970 Pine Point Mines reported reserves at the end of 1969 of 41.8 million tons averaging 2.4% lead and 6.3% zinc. Studies on underground mining are in progress as a percentage of the total reserves contained in more deeply buried ore bodies cannot be mined by open pit methods because of an adverse stripping ratio.

APPENDIX B

This appendix consists of a brief log of a reference core, Pine Point area, District of Mackenzie, to provide a reference section of the Sulphur Point Formation. The core is stored with the Institute of Sedimentary and Petroleum Geology, Calgary, Alberta.

Hole No. 262, Pine Point Mines Ltd., Pine Point N.W.T.
Lat. 60° 45' N., Long. 114° 48' W.
Elev. 755 feet.
Total Depth: 428.8 feet
Core Size: 1.25 inches.

Footage in Hole	Thickness	Lithology
0-44	44	Overburden.
SLAVE POINT FORMATION		
44-47	3	Limestone. Light brown, medium calcarenite with abundant small brachiopod shells and 1-2 inch cabbage-shaped stromatoporoids. Micritic zones in stroms. Poorly defined bedding. Non-porous.
47-77.2	30.2	Limestone. Thinly laminated, light brown, fine-grained, with fine wispy argillaceous banding. Scattered small _Amphipora_, small brachiopods. Rounded micritic algal (?) lumps up to 1 inch, lumps have oncolitic coatings at 52 ft. Argillaceous partings are from 1/10 inch to 6 inches apart. Non-porous.
77.2-80	2.8	Limestone. Brown biosparite and biosparrudite. Non-porous.
80-82	2	Limestone. Brown biomicrite with scattered whole small brachiopod shells. Non-porous.
82-88	6	Limestone. Medium brown biosparite with abundant wispy argillaceous partings and abundant scattered tiny brachiopods and ostracods (?). Non-porous.
88-89	1	Limestone. Micrite, light brown, with erratic 1 mm. sparry calcite blebs. Minor oil stain. Poor vuggy porosity.

Footage in Hole	Thickness	Lithology
89-96	7	Limestone. Creamy to light brown micrite with very closely spaced microstylolites and fine argillaceous laminations. Non-porous.
96-98	2	Limestone. Light brown micrite with erratic sparrite blebs. Poor inter-particle porosity. Vertical fractures.
98-105	7	Limestone. Bedded, light brown biomicrite and intramicrite. Non-porous.
FORT VERMILION FORMATION		
105-112	7	Limestone. Light grey to light brown, fine-grained, mottled and disturbed algal laminations; dolomitic in places; some large calcite clusters and calcite-lined vugs, some possibly replacing gypsum blebs since laminations bend around them. Poor porosity.
112-114	2	Limestone. As 105-112, but milky white and clear sparry calcite blebs and bands (after gypsum) comprise most of the rock. Fair vuggy porosity.
114-116	2	Limestone. Laminated, fine-grained, dolomitic with extensive dark grey mottling. Laminations somewhat disturbed in places. Non-porous.
116-120	6	Limestone. As 112-114, but with some remnants of laminated and mottled rock between calcite blebs. Fair vuggy porosity.
120-121	1	Limestone. As 112-114. Calcite occurs in vugs as coarse crystals coated with bitumen. Brecciation and collapse have occurred with invasion of white and clear calcite. Some milky-white dolomite surrounds vugs. Fair vuggy porosity.
121-123	2	Limestone. Laminated micrite with calcite lining a zone of layered vuggy porosity. The last stage was preceded by a layer of bitumen coating earlier crystals. Fair vuggy porosity.
123-127	4	Limestone. Medium to dark brown

Footage in Hole	Thickness	Lithology
		dismicrite with disturbed algal laminations. Penetration of bitumen into pores follows laminations. Four inches of extremely finely laminated carbonaceous limestone at 126.5 ft. Non-porous.
127-127.5	0.5	Shale. Badly disintegrated bluish grey calcareous shale.
127.5-138.5	11	Limestone. Dark greyish brown micrite with poorly developed to well-developed laminations accentuated by bitumen. Slightly dolomitic with fine sucrosic texture developed in places. Non-porous.
138.5-139	0.5	Limestone. Amphiporid biomicrite (<u>Amphipora</u> about 2 mm. in diam.) Minor amounts of small brachiopod shells. Non-porous.
139-142	3	Limestone. Similar to 127.5-138.5, argillaceous with dark grey mottling toward base. Non-porous.
(Amco Marker) 142-154	12	Amco Marker. Very argillaceous bluish grey limestone with crude laminations and dark grey mottling due to disseminated pyrite. Upper and lower contacts gradational, contacts arbitrary. Non-porous.
154-156	2	Limestone. Medium brown, fine biosparite with micritic intraclasts up to 2 cm. and subspherical stromatoporoids. Stromatoporoids contain sparry calcite pseudomorphs after anhydrite replacement. Non-porous.
156-159	3	Limestone. Buff to light brown micrite with scattered sparry calcite blebs. Some chalky zones with minor porosity developed parallel to bedding.
159-161	2	Limestone. Light brown micrite with 1 cm. horizontal bands of coarsely crystalline milky white calcite giving brown and white striped appearance to the rock. Poor vuggy porosity.
161-163	2	Limestone. Buff micrite with algal (?)

Footage in Hole	Thickness	Lithology
		laminations emphasized by bitumen from oil penetration. Non-porous.
163-172.5	9.5	Limestone. Light brown to grey micrite, dolomitic in places with dark grey mottles.
172.5-178	5.5	Limestone. Cream coloured pelmicrite with abundant small stylolites. Non-porous.
SULPHUR POINT FORMATION		
178-226.5	48.5	(Watt Mountain Formation of Norris, 1965) Brilliant waxy green shale bands interspersed with white limestone. Upper shaly bands are rich in charophytes. Shales occur: 6 inches starting at 187 ft., 3 in. at 188 ft., 2 in. at 225 ft., 6 in. at 226 ft. Limestone is mainly fine to medium biosparite with some biosparrudite beds and some gastropod pelmicrites. The whole unit is bedded. Bedding and porosity are emphasized by very extensive penetration of pores by bitumen. Scattered zones of large anhydrite crystals up to 1 inch long, (pseudomorphed by sparry calcite). Non-porous.
226.5-230	3.5	Limestone. Buff to creamy coloured biosparite and biopelsparite rich in <u>Amphipora</u> and <u>Stachyodes</u>. Some pores are filled by bitumen. Stylolites very common. Zones of sparry calcite after anhydrite scattered throughout. Non-porous.
274.5-279	4.5	Dolomite and calcite mixture. Buff pelsparite remnants surrounded by lighter coloured alteration zones, white sparry dolomite and calcite, and native sulphur. Poor vuggy porosity.
279-284	5	Limestone. Buff to dark brown laminated biopelsparite with common <u>Amphipora</u> and <u>Stachyodes</u>. Native sulphur chokes fine vugs, intrafossil and interparticle porosity. Stylolites very abundant. Non-porous.
PRESQU'ILE FORMATION		
284-297	13	Dolomite. Very coarsely crystalline

Footage in Hole	Thickness	Lithology
		white sparry dolomite with remnants of medium-brown dolomite "floating" in it. Relict textures where brown dolomite predominates indicate abundant thick brachiopod shells, amphiporids, and gastropods, prior to dolomitization. Good vuggy porosity.
297-304	7	Dolomite. Finely crystalline sucrosic dark brown dolomite with fair vuggy and poor intercrystalline porosity. Some fine bioclastic relicts and some large calcite-filled vugs (after anhydrite blebs?).
304-310	6	Dolomite. <u>Amphipora</u> bed invaded by varying amounts of coarse white sparry dolomite. Good leach-fossil vuggy porosity.
310-219.5	9.5	Dolomite. Medium-grey to dark brown coarsely crystalline dolomite with varying amounts of white sparry dolomite -- up to 50% in some sections. Some pseudobreccia and minor laminated fabrics.
319.5-326	6.5	Dolomite. Medium to dark brown, coarsely crystalline, originally an amphiporid bed. Good intercrystalline and intrafossil vuggy porosity. Fossils vary from distinct to completely unrecognizable.
(C Marker Bed)		
326-342	16	C Marker Bed. Dolomite. Medium-brown, fine- to medium-crystalline, sucrosic brown dolomite with some argillaceous beds and some laminated zones about 3-6 inches thick. Abundant large calcite and native sulphur-filled vugs with banding bending around them are presumably relicts after anhydrite blebs. Good intercrystalline porosity and leach fossil vuggy porosity in scattered amphiporid zones.
342-348	6	Rubble. Mixture of dolomite, coarse calcite cleavage fragments and shaly material. Five foot cave reported. Probably solution cavern.
348-368	20	Dolomite. Light-grey to dark brown very

Footage in Hole	Thickness	Lithology
		coarsely crystalline dolomite with scattered bands of white and grey sparry dolomite. Minor vuggy porosity. Abundant algal-type laminations persist through into extremely coarsely crystalline material in places. Possibly some packed amphiporid zones. Minor slump (?) brecciation, calcite, and sulphur-filled vugs occur toward the base of the interval. Base of Presqu'ile taken arbitrarily at the base of coarsely crystalline dolomite and abundant white sparry dolomite. Contact gradational.
PINE POINT FORMATION		
368-390	22	Dolomite. Medium crystalline, sucrosic brown dolomite with good intercrystalline porosity. Very well laminated, with bitumen in pores often emphasizing laminations. Some sulphur in pores.
390-399	9	Dolomite. Medium brown, finely crystalline dolomite with fair pin point and leach-fossil vuggy porosity. More coarsely crystalline, with amphiporids and remnants of platy stromatoporoids (or coralline algae) in lower 3 feet.
399-409.5	10.5	Dolomite. Laminated with carbonaceous laminae, in places distorted. Cut by subhorizontal calcite-sulphur veinlets in place. Mainly medium crystalline brown dolomite with good intercrystalline porosity.
409.5-418	8.5	Dolomite. Cohesive finely crystalline, bluish grey, laminated with some subhorizontal mottling and fair vuggy porosity.
418-426	8	Dolomite. Medium crystalline, brown, with good intercrystalline porosity.
426-428.8	2.8	Dolomite. Medium brown, finely crystalline cohesive dolomite with fair pin point and leach-fossil vuggy porosity.
		End of Hole.

APPENDIX C

PALEOECOLOGY OF FOSSILS FROM THE STUDY AREA

Paleoecological interpretations based on studies by previous workers on well-preserved limestone accumulations form the basis for much of the interpretation of the severely dolomitized carbonate rocks of the study area. From consideration of the fossils from the study area in the light of both these interpretations, and the ecology of modern counterparts, conclusions can be reached regarding their paleoecology. The environmental interpretation for each fossil group listed in Table 3 (text) is discussed here. The areal distribution of most types of fossils in the study area is shown on Figs. 8-10, and A15-A17. Most authors discuss the growth sites of organisms relative to a 'reef' (fore-reef, reef, back-reef, etc.) and this terminology is retained here to indicate general environments, though the presence of a reef is not necessarily inferred for the study area where analogies are drawn to other Devonian carbonate complexes.

Stromatoporoids

Stromatoporoids of the study area are grouped into four categories: 1. subspherical (massive), 2. platy or tabular, 3. *Stachyodes* (dendroid), and 4. *Amphipora* (dendroid). The platy or tabular stromatoporoid group may include some coralline algae, as dolomitization commonly has obscured all details except external shape. Subdivision of stromatoporoids on the basis of shape alone as an indication of environment may be questioned (Dr. C.W. Stearm, pers. comm. 1969) but a number of studies e.g. Klovan (1964), Murray (1966) and Fishbuch (1968) indicate that there is considerable justification for subdivision on this basis. No modern representatives of stromatoporoids exist but

they are thought to closely resemble modern hydrocorallines. The precise growth site of types 1 and 2 above, within an accumulating reef complex has been debated at length but for most purposes of this study the general position is sufficient. In Devonian reefs, they usually formed the massive framework on the edges of reef complexes, analagous to the reef front found in modern reefs of the Great Barrier Reef as described by Maxwell (1968, p.106). In Devonian reefs, the subspherical (massive) stromatoporoids are generally believed to have occupied the turbulent water zone, while the platy and tabular types grew in less turbulent to quiet (deeper) water mainly on the seaward side of the reef front (Klovan, 1964, p.37; Lecompte, 1956, p.49; Murray, 1966, p.16; Fishbuch, 1968, pp.500-502; Corneil, 1969, p.41).

There is also general agreement among the writers quoted above on the sites of growth of the dendroid stromatoporoids Stachyodes and Amphipora. Stachyodes apparently grew immediately in front of and behind the reef front in areas of good circulation of water. Amphipora generally represent the quiet water lagoonal environment and could withstand restriction of water. Jamieson (1966, Table 7) compiled environmental interpretations for Amphipora (which she considered to be related to algae rather than stromatoporoids) from 23 occurrences (16 references). Of these occurrences, 11 were interpreted as back-reef, 11 lagoonal, and 6 reef flat, 6 reef front and 3 fore-reef. Jamieson (1966, p.166) concluded that Amphipora preferred back-reef areas in the Alexandra reef-complex.

As Corneil (1969, p.46) noted: "By employing in-place massive stromatoporoids and Amphipora, the paleoecologist can gain a primary indication of turbulent versus quiet-water and deep versus shallow-water

environments." In addition, _Amphipora_ are good indicators of a lagoonal or back-reef environment. The occurrence of massive and platy stromatoporoids toward the north and _Amphipora_ toward the south of the study area (Figs. 8-10, A15-A17) indicate a more open marine area to the north and restricted quiet water toward the south.

Corals

Three groups of corals are recognized in the study area: 1. rugose (horn) corals, 2. _Thamnopora_, and 3. other colonial corals. All of these are thought to have grown in warm shallow seas similar to modern warm-water corals.

Only a few colonial corals have been recognized, but they are scattered and do not provide a basis for zonation of the reef. _Thamnopora_ and rugose corals are common along the northern margin of the study area. In other studies of Devonian carbonate complexes _Thamnopora_ and rugose corals occur on the fore-reef slope and in muddy environments but are also found in sediments of the turbulent zone and quiet water sediments of the back-reef (Edie, 1961, p.283; Klovan, 1964, p.40; Lecompte, 1968, p.36; Murray, 1966, p.20; Playford and Lowry, 1966; and Playford, 1967). Their occurrence in a belt along the northern margin of the study area (Figs. 8-10, A15-A17) indicates deeper water and fore-reef sediments in this area.

Brachiopods

Brachiopods of the study area have been divided into three groups:

1. Thick-shelled; _Stringocephalus_ and _Warrenella_, commonly broken and abraded.

2. Thin-shelled; mainly atrypids, commonly unfragmented and articulated.

3. Chitino-phosphatic; Lingula, usually whole and lying flat on bedding planes.

Their mode of occurrence and the nature of the surrounding sediments are good environmental indicators. The thick-shelled brachiopods are usually found in biosparites, and some beds of brachiopod biosparite are composed entirely of broken, abraded, and well-sorted brachiopod fragments. The thin-shelled brachiopods are commonly articulated but are also often disarticulated and sometimes broken. They are usually enveloped by argillaceous carbonate, calcareous shale or bituminous carbonate and often have crinoid ossicles associated with them. Lingula occurs only in foetid argillaceous bituminous limestones. The distribution of the brachiopods in three belts (Figs. 8-10, A15-A17) with Lingula to the north, thin-shelled types intermediate, and thick-shelled types to the south indicates shallowing of water from deeper water to the north with shallower more turbulent water further south over the belt containing Stringocephalus and other thick-shelled brachiopods.

Brachiopods have been found in rocks deposited in muddy quiet environments of the fore-reef area by Leavitt (1968, p.327) and Corneil (1969, p.52), and in a diversity of reef and fore-reef environments by Klovan (1964, p.20). Edie (1961, p.283) concluded that brachiopods inhabited quiet, muddy environments of normal marine salinity. It appears that the brachiopods of the study area have a distribution similar to that in other Devonian reefs.

Gastropods

Gastropods of both low and high-spired types have been found occasionally in the limestones of the Sulphur Point Formation (Fig.A17). They are abundant only in some biopelsparites and pelsparites. As in

modern reef environments, gastropods were adapted to a wide range of environments (Klovan, 1964, p.41; Jamieson, 1966, p.169) and the few occurrences cannot be used to indicate any particular zonation of the carbonate complex.

Crinoids

Crinoid ossicles have a distribution closely parallel to that of the thin-shelled brachiopods in all strata below the Slave Point Formation. They are most abundant in the shales and argillaceous bituminous limestones toward the north of the study area but also occur in the dolomite of the Pine Point Formation. In conjunction with other criteria they appear to be good indicators of quiet waters of normal marine salinity and muddy environments of basinal and fore-reef areas, but as they can be transported easily, care is necessary in their usage as environmental indicators. Edie (1961), Klovan (1964, p.41), Murray (1966, p.21), and Corneil (1969, p.51) and Jamieson (1966, p.170) are generally in agreement on the growth of crinoids in the basinal and fore-reef areas, with some occurrences within the reef itself, and a general absence in lagoonal deposits. Leavitt (1968, p.328) concluded that the crinoids were transported into the quiet water environments from growth sites in sheltered parts of the reef and slightly agitated waters of the fore-reef slope.

Ostracods

Ostracods have been identified from many of the limestones of the Slave Point Formation. They cannot be used as a group as environmental indicators as they have been found in many parts of reef complexes by Klovan (1964, p.328), and Jamieson (1966, p.171).

Algae

Algal material identified falls into four categories:

1. Oncolites and algal crusts.
2. Green and blue-green algal mats (inferred from laminites, and stromatolites).
3. Calcispheres (algal affinity).
4. Charophytes.

Each of these can be used as an indicator of a fairly specific environment. There may also be some dolomitized coralline algae that have been grouped with platy stromatoporoids.

Oncolites, and algal crusts and rims on fossil fragments (commonly stromatoporoids) and calcispheres are found in limestones of the Sulphur Point Formation and some oncolites occur in the Slave Point limestones. Algal mats are inferred for laminites (stromatolites) in parts of all formations studied. Charophytes are confined to the bright-green shale facies (Watt Mountain).

Oncolites, algal crusts and algal micrite rims on fossil fragments all indicate accumulation in the photic zone since algae depend on photosynthesis for their life processes, and flourish best in areas of good circulation. Oncolites are good indicators of shallow, at times turbulent, water where they are overturned by waves and tidal currents.

Algal stromatolites are found in modern intertidal to supratidal environments in protected areas (Ginsburg, 1957, p.93; Illing, Wells and Taylor, 1965, p.93; Kendall and Skipwith, 1969, p.854; personal observations, Crane Key in Florida Bay). They apparently are not confined to this zone as Gebelein (1969) has described them from the subtidal zone in Bermuda. However, in conjunction with dessication-cracks, gypsum/

anhydrite nodules, etc., they are indicators of shallow water environments subject to periodic exposure.

Calcispheres, which may be reproductive phases of algae, have commonly been found in back-reef lagoonal rocks of Devonian reef complexes (Klovan, 1964, p.42; Jamieson, 1967, Table 8). Their occurrence in pelsparites and biopelsparites of the study area is in agreement with these conclusions. Calcispheres have not been plotted onto Fig.A17 because thin sections are necessary for their positive identification and thin sections were not prepared for a sufficient number of limestones to prepare a sound plot of distribution.

Charophytes are fresh-water to brackish water plants (Peck and Morales, 1966, p.303) and it is interpreted that they lived in fresh to brackish waters of the Devonian. Their restriction to the bright-green shale facies (Watt Mountain) which lies on irregular bedding surfaces, often with a rubble zone, supports the conclusion that the Charophyte-bearing shales represent fresh to brackish water deposition.

Trilobites

Only a few occurrences of trilobite fragments were recorded in the study area (due perhaps to lack of preservation). No conclusions can be drawn from them as trilobites occupied a wide range of marine environments.

Tentaculitids

Tentaculitids are abundant in the bituminous shale, limestone and dolomite member of the Pine Point Formation (Fig.A15). They were not noted elsewhere (lack of preservation?). Leavitt (1968, p.328) and Edie (1961) found them most commonly in argillaceous (off-reef) limestones

with some in the reef complex. Laporte (1969, p.105) recognized <u>Tentaculites</u> from the tidal flat-lagoon environment of the Manlius Formation, which would appear to be a different environment than that in which the bituminous, shale, limestone and dolomite of the study area was deposited. Bilan (1961) indicated two distinct types of <u>Tentaculitids</u>: thin and thick-shelled, but concluded that they still could not be used as environmental indicators, though thin-shelled forms are pelagic and thicker-shelled forms benthonic.

APPENDIX D

TABLE 1: LEAD ISOTOPE RATIOS FROM THE PINE POINT AREA: A COMPILATION.

Sample	Pb^{206}/Pb^{204}	Pb^{207}/Pb^{204}	Pb^{208}/Pb^{204}
1. Pine Point, ave. of eight runs.*	18.305	15.786	38.667
2. Prairie Lake Area (PIP4)#.	18.27	15.73	38.59
3. As above (PIP3).	18.26	15.73	38.55
4. Diamond D.H. 1361 208.5'.	18.26	15.72	38.52
5. D.D.H. K57-8 @ 81.5'.	18.29	15.75	38.59
6. D.D.H. J70-5 @ 72'.	18.28	15.74	38.60
7. O42 pit.	18.24	15.69	38.46
8. N32 pit (No. PP49).	18.31	15.79	38.59
9. O42 pit (No. PP62).	18.23	15.71	38.51
10. O42 pit (No. PP55).	18.25	15.76	38.50
11. GENX Group.	18.25	15.76	38.40
12. N.L.Z. Claims.	18.69	15.91	38.68
13. Windy Point.	18.25	15.76	38.40
14. Best fit model age of 210 m.y.			

SOURCES:

* No.1. D.K. Robertson, University of Alberta analyses (Cumming and Robertson, 1969).

\# No. 2-10. D.K. Robertson, University of Leeds analyses (unpublished, uncorrected for Pb204 scatter).

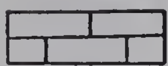
No. 11, 12, 13. Russell and Farquhar (1960), University of Toronto.

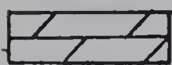
No. 14. R.S. Cannon, U.S. Geological Survey, from data in (1), personal communication to Dr. R. E. Folinsbee.

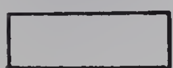
APPENDIX E: STANDARD LEGEND FOR CROSS SECTIONS, FIGS.A2-A14.

NOTE: THE MAJOR PORTION OF EACH FACIES FALLS WITHIN THE FORMATION INDICATED HERE, BUT EACH FACIES MAY ALSO OCCUR IN OTHER FORMATIONS.

SLAVE POINT FORMATION

 BEDDED BROWN FINE-GRAINED LIMESTONE FACIES

 MOTTLED DOLOMITE FACIES

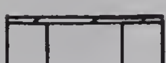
 ARGILLACEOUS DOLOMITIC LIMESTONE FACIES (AMCO)

FORT VERMILLION FORMATION

 GYPSIFEROUS LIMESTONE/DOLOMITE FACIES

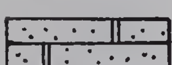
 LAMINATED BROWN LIMESTONE AND MOTTLED DOLOMITE FACIES

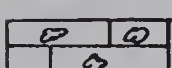
SULPHUR POINT FORMATION

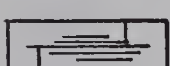
 WHITE BIOSPARITE-PELSPARITE FACIES (UNDIFFERENTIATED)

 WHOLE-FOSSIL WHITE BIOSPARITE-PELSPARITE SUB-FACIES

 BIOSPARRUDITE SUB-FACIES

 BIOSPARITE SUB-FACIES

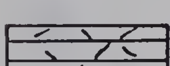
 PELSPARITE SUB-FACIES

 BRIGHT-GREEN SHALE FACIES (WATT MOUNTAIN)

 NON-LAMINATED BROWN LIMESTONE AND MOTTLED DOLOMITE FACIES

PRESQU'ILE FORMATION

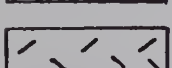
 UNDIFFERENTIATED COARSELY CRYSTALLINE DOLOMITE FACIES

 LAMINATED VUGULAR DOLOMITE SUB-FACIES

 LATTICEWORK DOLOMITE SUB-FACIES

 DOLOMITE WITH ANHYDRITE PSEUDOMORPHS SUB-FACIES

 FRIABLE BROWN DOLOMITE FACIES (C MARKER BEDS)

 COHESIVE BROWN DOLOMITE FACIES (D3 MARKER)

PINE POINT FORMATION

 FRIABLE BROWN DOLOMITE FACIES

 COHESIVE BROWN DOLOMITE FACIES

LAMINATED BROWN DOLOMITE SUB-FACIES

BIOCLASTIC BROWN DOLOMITE SUB-FACIES

BITUMINOUS LIMESTONE/DOLOMITE FACIES

COELENTERATE BIOLITHITE AND RUBBLE FACIES

BUFFALO RIVER FORMATION

DARK-GREEN SHALE FACIES

SYMBOLS

W.V.D.	WHITE VEIN DOLOMITE
Cht.	CHERT
Gyp.	GYPSUM
#	GYPSIFEROUS
	STROMATOPOROIDS (SUB-SPHERICAL, PLATY)
	CORALS: SOLITARY, COLONIAL
	<u>THAMNOPORA</u>
	<u>AMPHIPORA</u>
	ECHINODERM FRAGMENTS
	BRACHIOPOD
	GASTROPOD
	SPOTTED DOLOMITE AND VAGUE FORMS (FOSSIL?)
	GALENA OCCURRENCE
	SPHALERITE OCCURRENCE
	GALENA AND SPHALERITE OCCURRENCE

ORANGE LINES ARE FORMATION BOUNDARIES; C MARKER OF THE PINE POINT FORMATION IS NOT OUTLINED UNLESS RELATIONSHIP NEEDS CLARIFICATION.

APPENDIX F

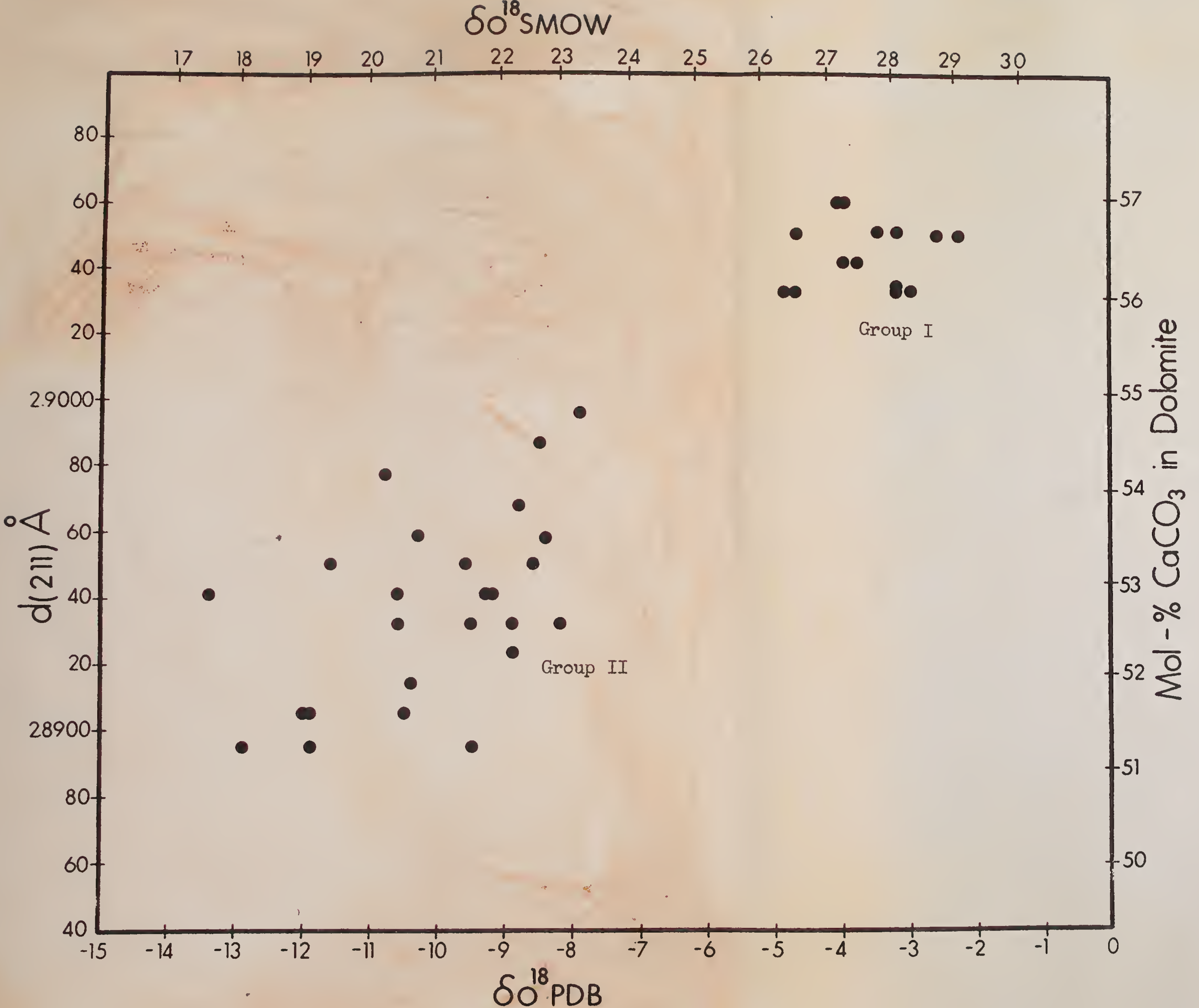
ISOTOPIC AND CHEMICAL COMPOSITION OF THE FORT VERMILION FORMATION

Initial results of the carbon and oxygen isotope studies on the carbonates in the Pine Point area indicated a distinct difference between finely crystalline 'sedimentary' and sucrosic to coarsely crystalline 'reef' dolomites (Fritz, 1969, Fig.3). Subsequent determinations of the mole % $CaCO_3$ in the 'sedimentary' dolomites indicated a positive correlation between the O^{18} and calcium carbonate content (Fig.F1). Two groups have been indicated: one with δO^{18} values of -1.0 to -4.0 per mil (PDB scale) and more than 55 mole % $CaCO_3$ and a second group with δO^{18} values of -6.0 to -12.5 per mil with less than 55 mole % $CaCO_3$.

When the values are plotted stratigraphically (Fig.A19, in pocket) it is obvious that the Group 1 dolomites (Fig.F1), with one exception, lie in two layers; one above and one below the Amco marker bed. In the exceptional case (Hole 217) designation of an Amco marker was questioned during initial logging as the interval appeared to be only slightly argillaceous. The group one dolomites are supratidal in nature. Most of the diagenetic and all of the hydrothermal dolomites fall in group two. Sodium (as halite or clays) and sulphur (as calcium sulphate) are both significantly enriched in the supratidal dolomites, further emphasizing the grouping. Electron microprobe analyses typically show that supratidal and diagenetic dolomites contain abundant clay inclusions.

These features exclude a post-Devonian recrystallization of the supratidal and diagenetic dolomites whose original composition may thus be closely retained, providing information concerning the geochemical and isotopic characteristics of the depositional environment. This data has been used in correlation of the Fort Vermilion Formation and may be of

much wider application. Research into such chemical and isotopic variations of carbonates is continuing at the University of Alberta.



δO^{18} SMOW
17 18 19 20 21 22 23 24 25 26 27 28 29 30
80 60 40 20 2.9000 80 60 40 20 2.8900 80 60 40
d(211) Å
57 56 55 54 53 52 51 50
Mol - % $CaCO_3$ in Dolomite
Group I
Group II
-15 -14 -13 -12 -11 -10 -9 -8 -7 -6 -5 -4 -3 -2 -1 0
δO^{18} PDB

FIG. A1: PINE POINT AREA

DIAMOND DRILL HOLE LOCATIONS
INDEX MAP FOR SECTIONS

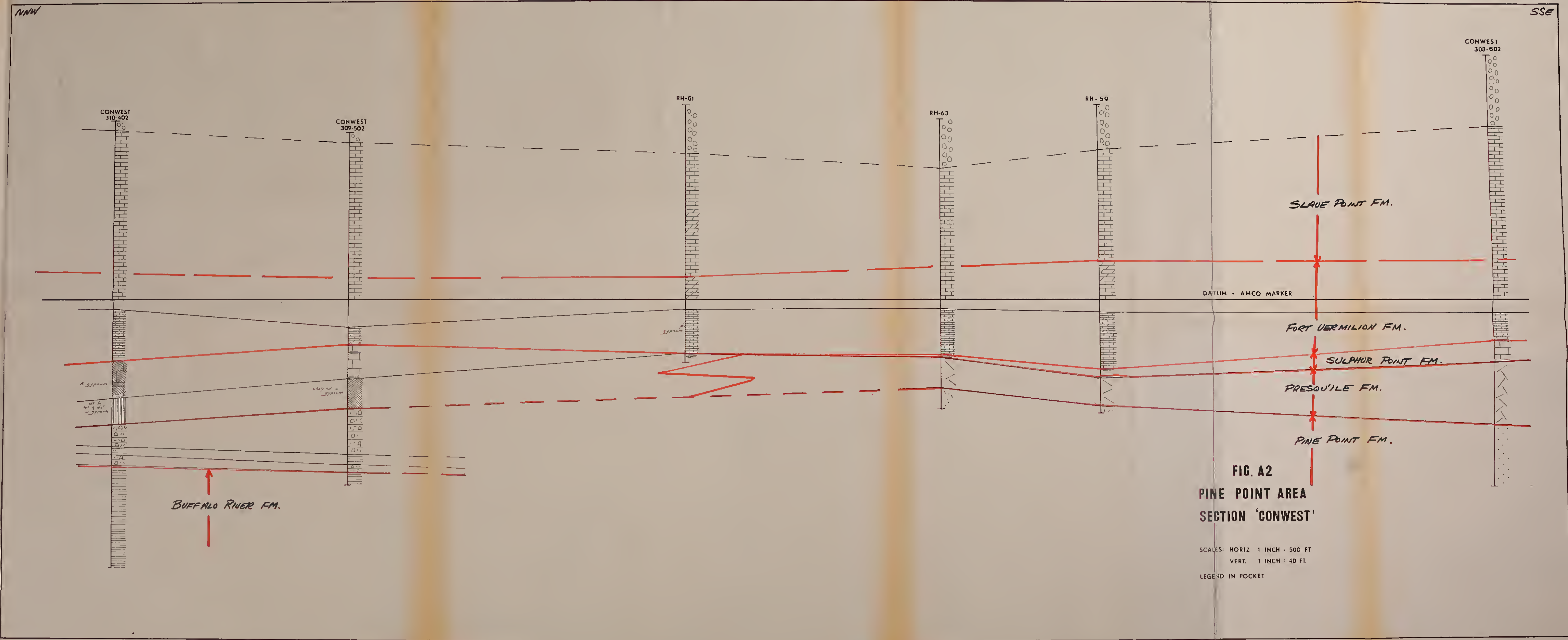


FIG. A2
PINE POINT AREA
SECTION 'CONWEST'

SCALES: HORIZ 1 INCH = 500 FT
VERT. 1 INCH = 40 FT.

LEGEND IN POCKET

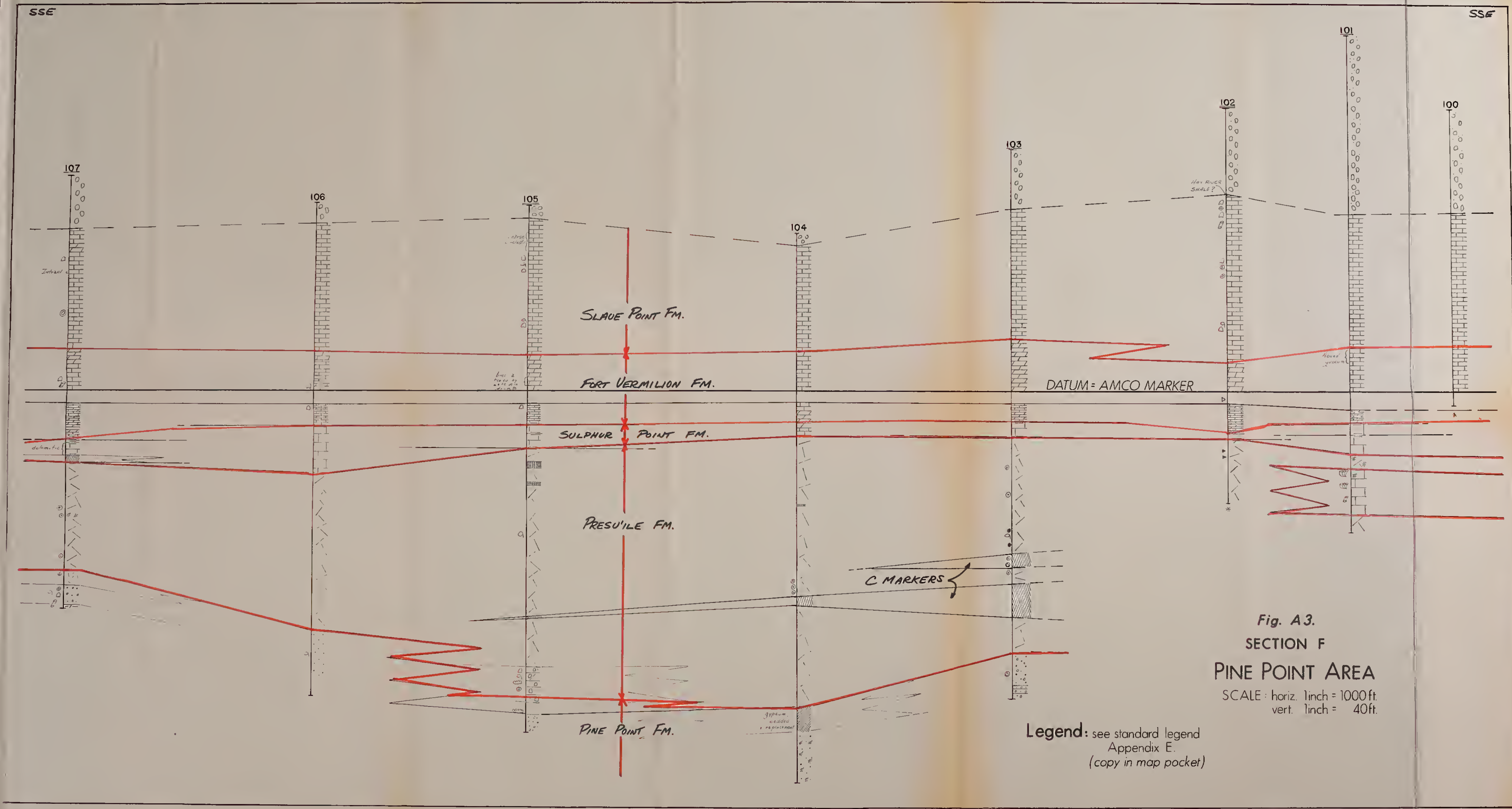
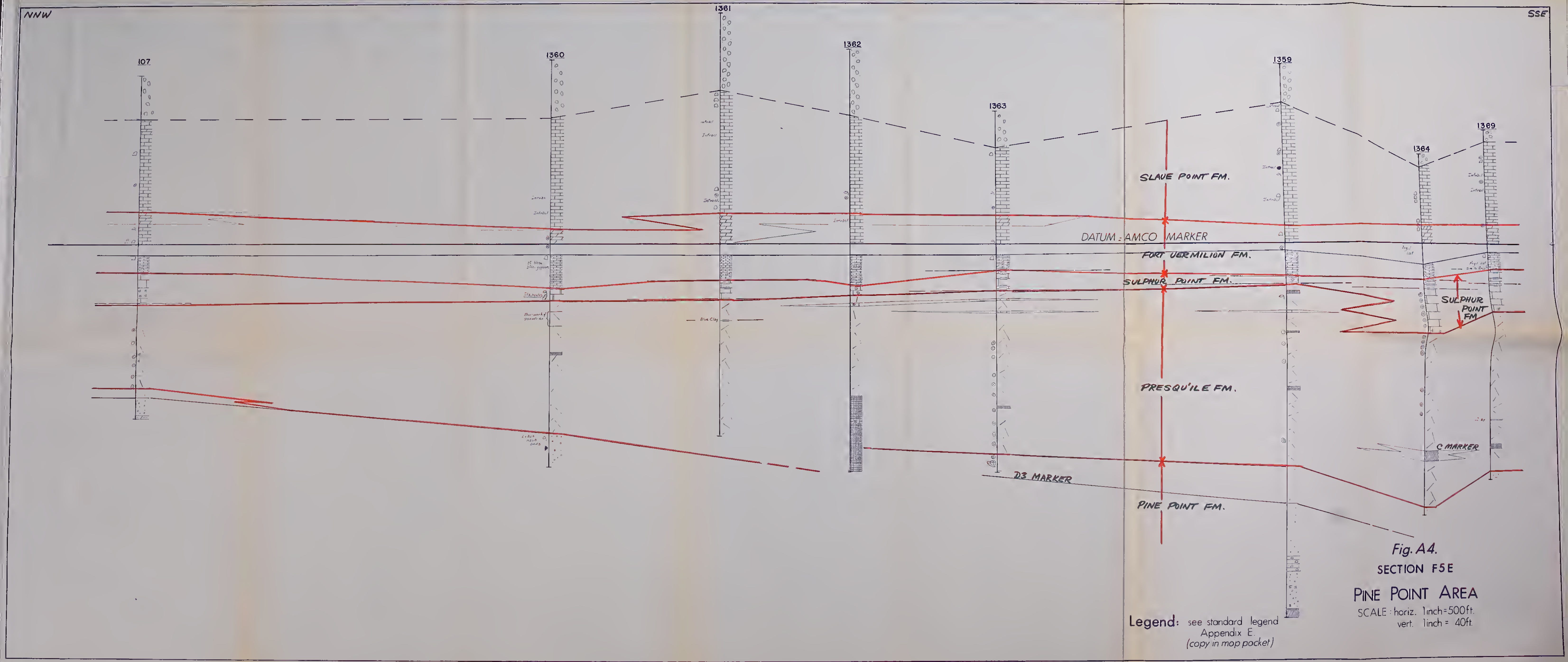


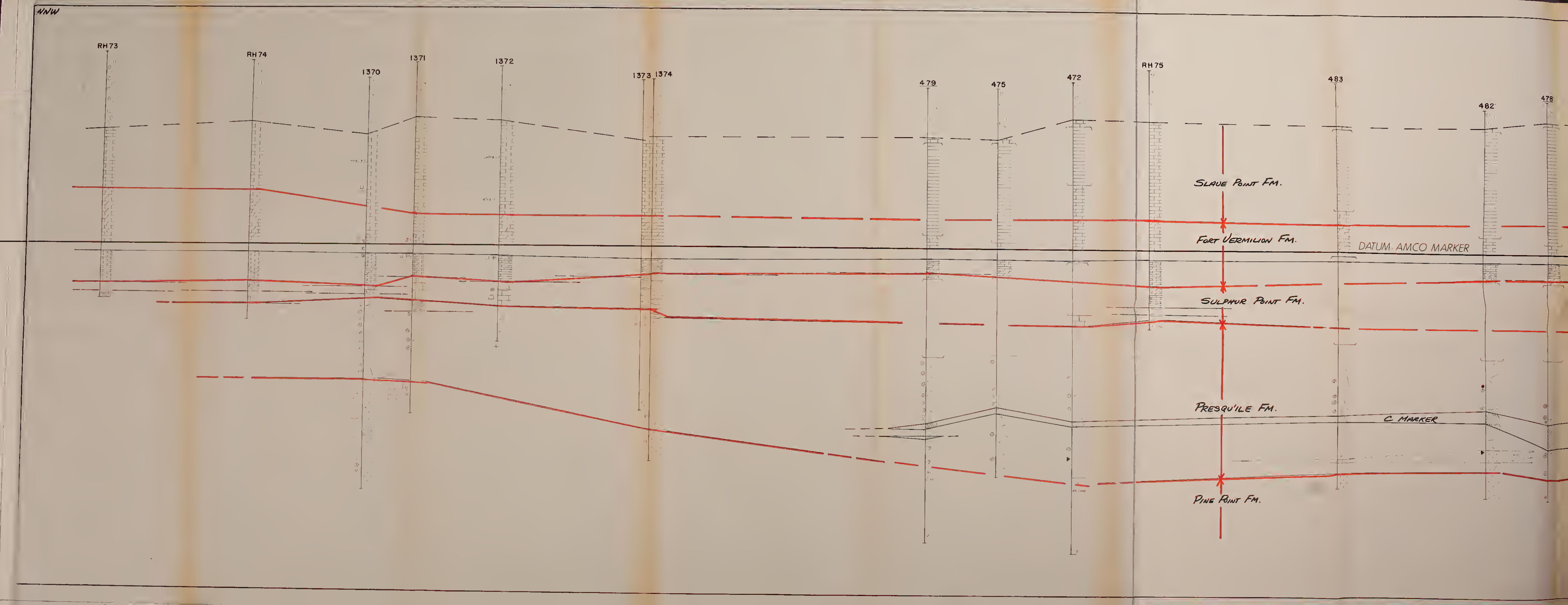
Fig. A3.
SECTION F
PINE POINT AREA
SCALE: horiz. 1inch = 1000ft.
vert. 1inch = 40ft.

Legend: see standard legend
Appendix E.
(copy in map pocket)



Legend: see standard legend Appendix E. (copy in map pocket)

Fig. A4.
SECTION F5E
PINE POINT AREA
SCALE : horiz. 1inch=500ft.
vert. 1inch = 40ft.



NNW
RH73
RH74
1370
1371
1372
1373
1374
479
475
472
RH75
483
482
478
SLAVE POINT FM.
FORT VERMILION FM.
DATUM AMCO MARKER
SULPHUR POINT FM.
PRESQU'ILE FM.
C MARKER
PINE POINT FM.

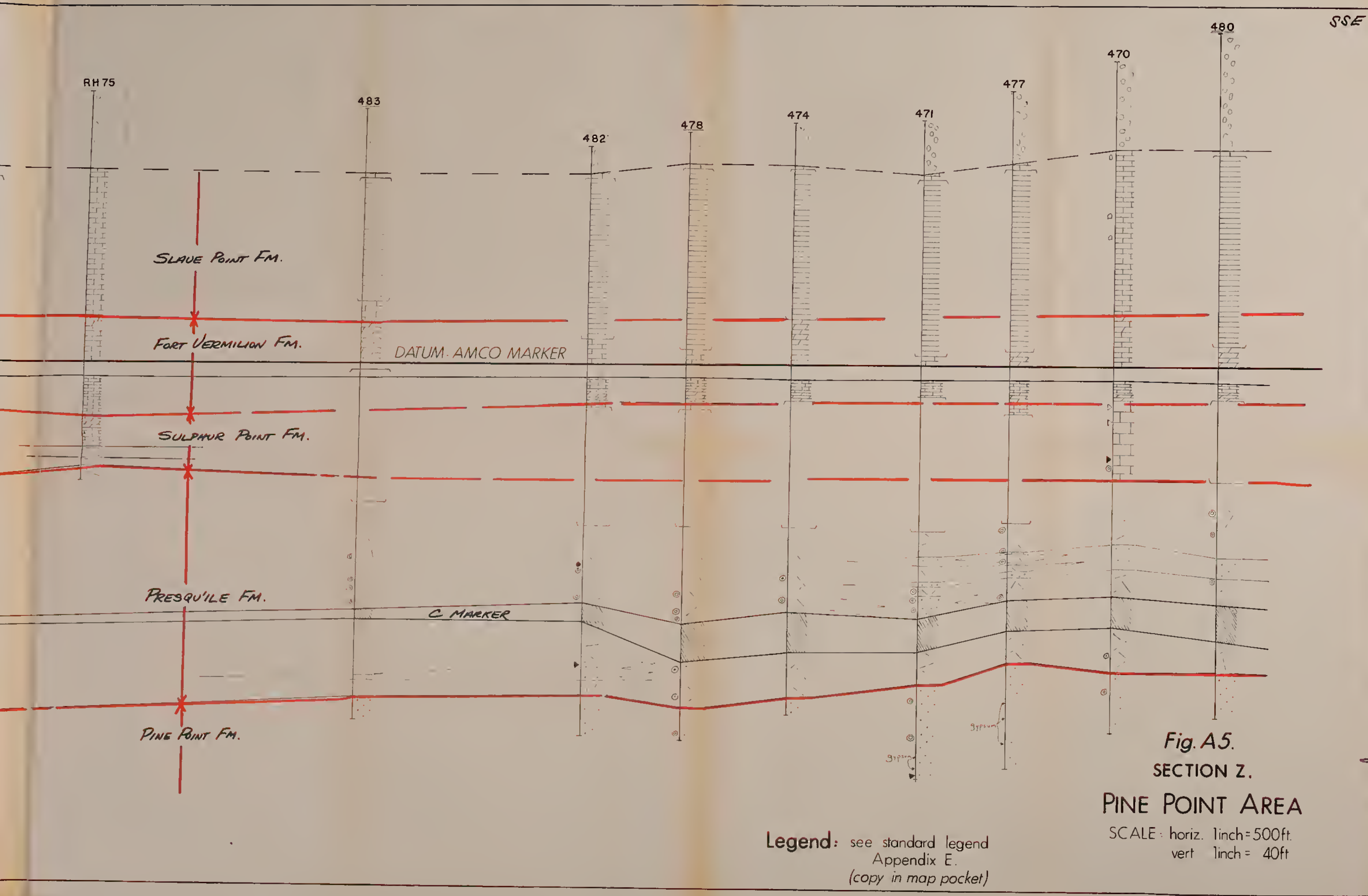
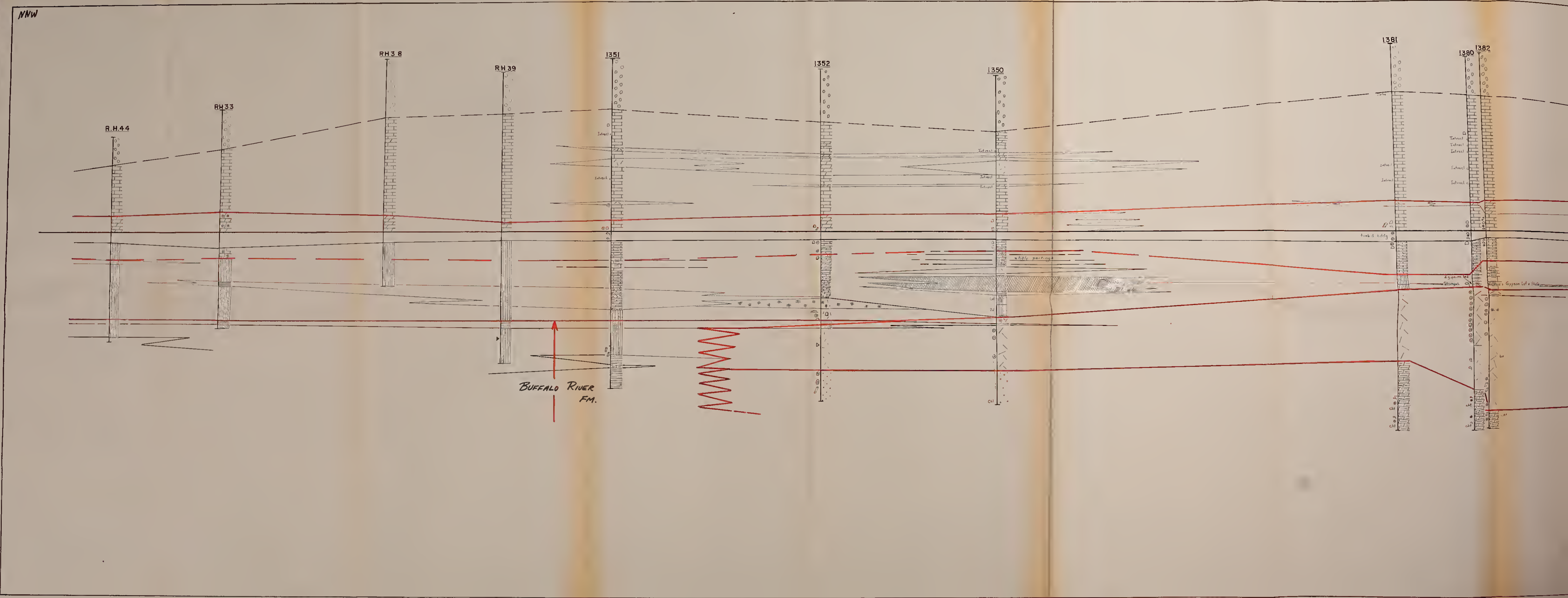


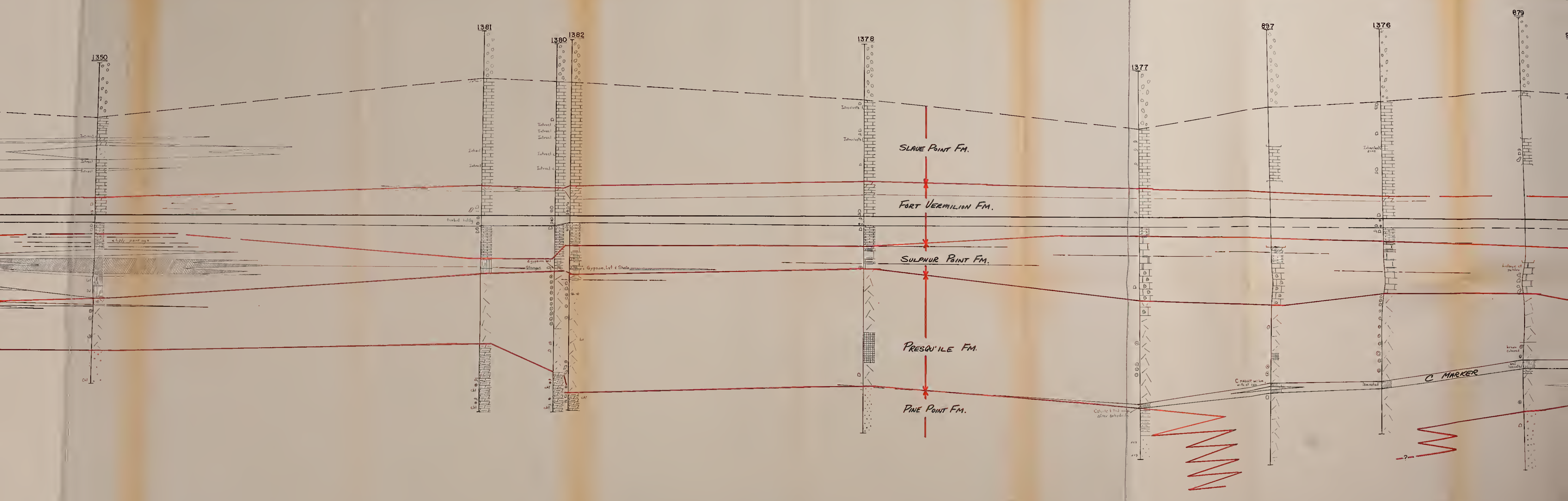
Fig. A5.

SECTION Z.

PINE POINT AREA

SCALE: horiz. 1inch = 500ft.
vert 1inch = 40ft


NNW
R.H.44
RH33
RH3 8
RH39
1351
1352
1350
1381
1380
1382
shale partings
BUFFALO RIVER
FM.



Legend: see standard legend Appendix E
(copy in map pocket)

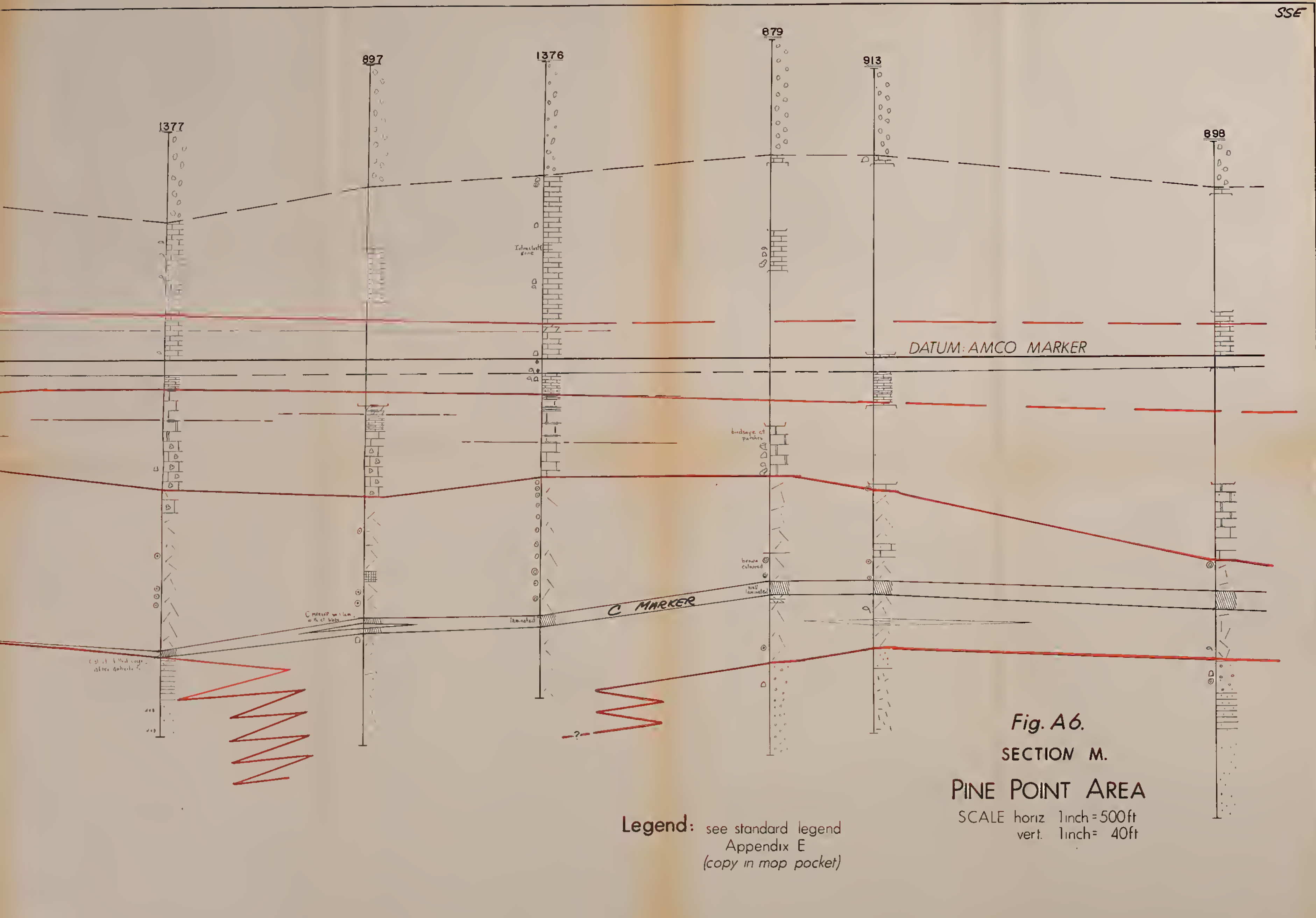


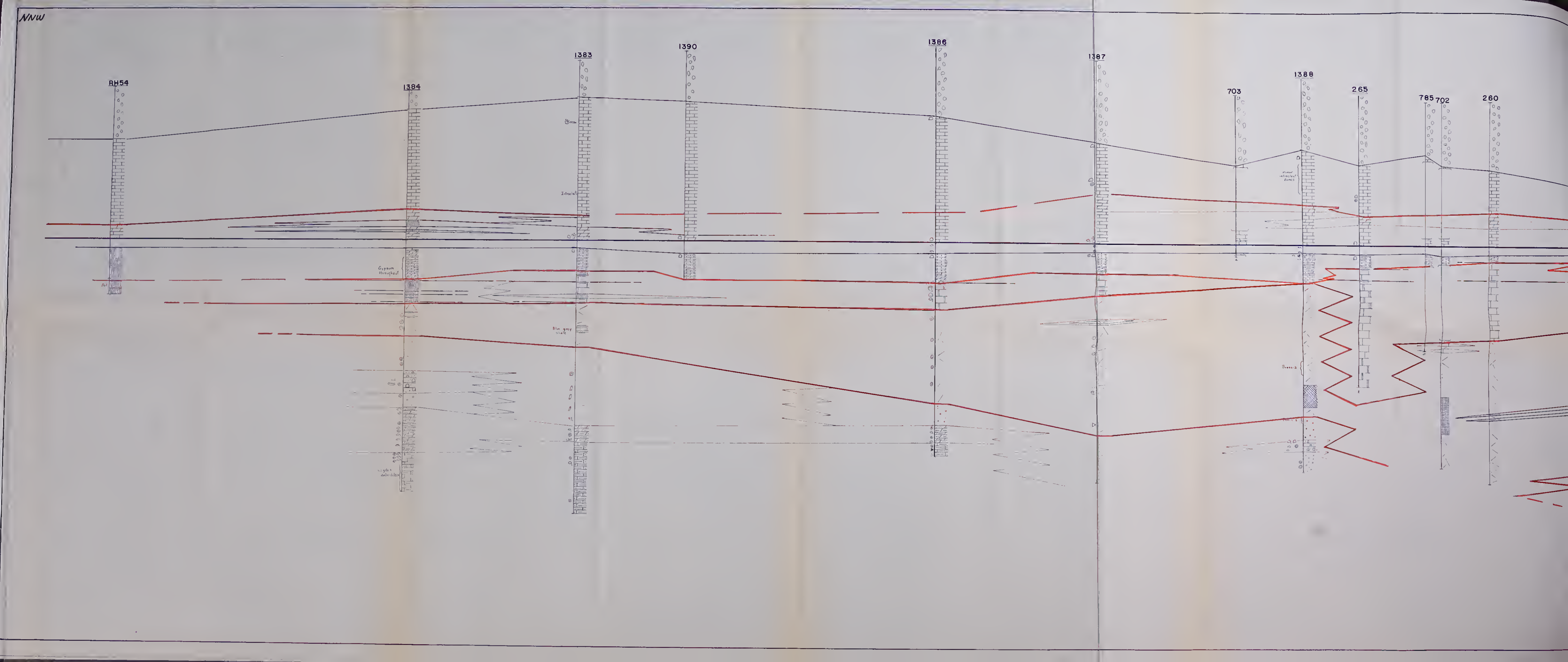
Fig. A6.

SECTION M.

PINE POINT AREA

SCALE horiz 1inch = 500ft
vert. 1inch = 40ft

Legend: see standard legend
Appendix E
(copy in map pocket)


NNW
RH54
1384
1383
1390
1386
1387
703
1388
265
785
702
260

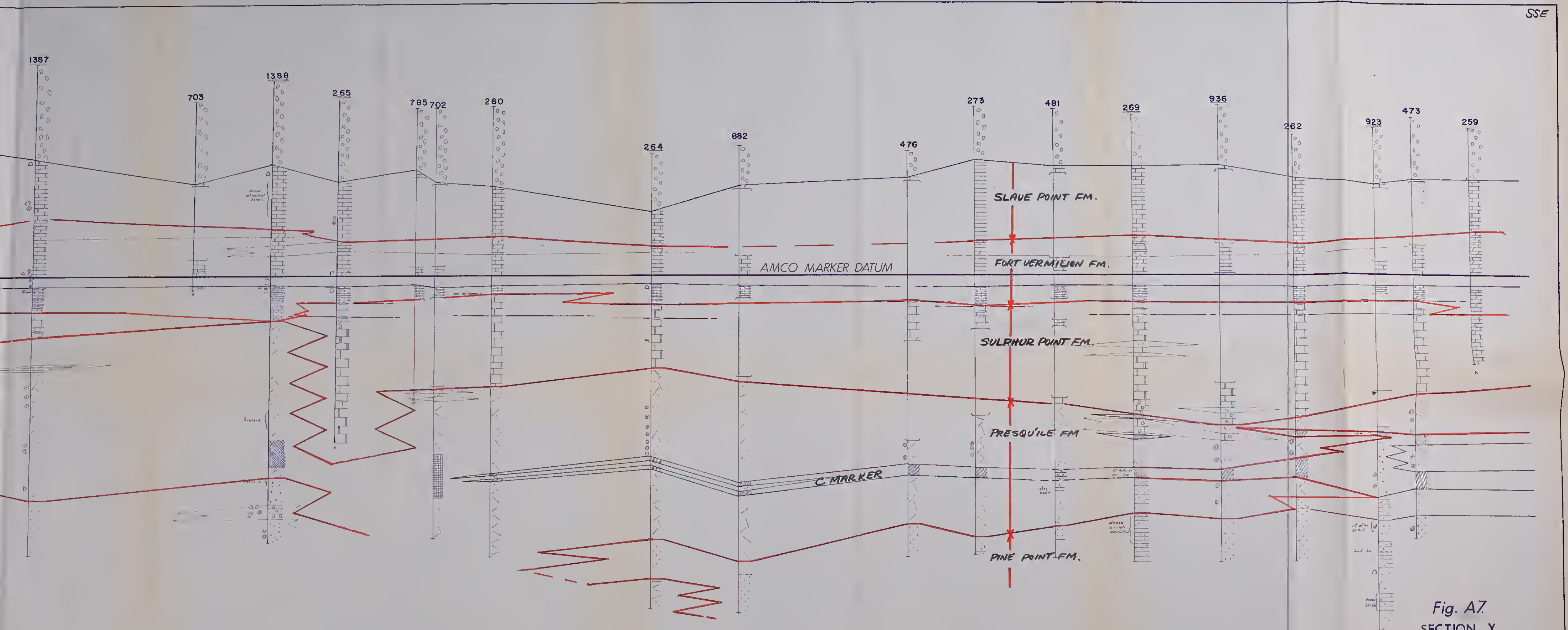
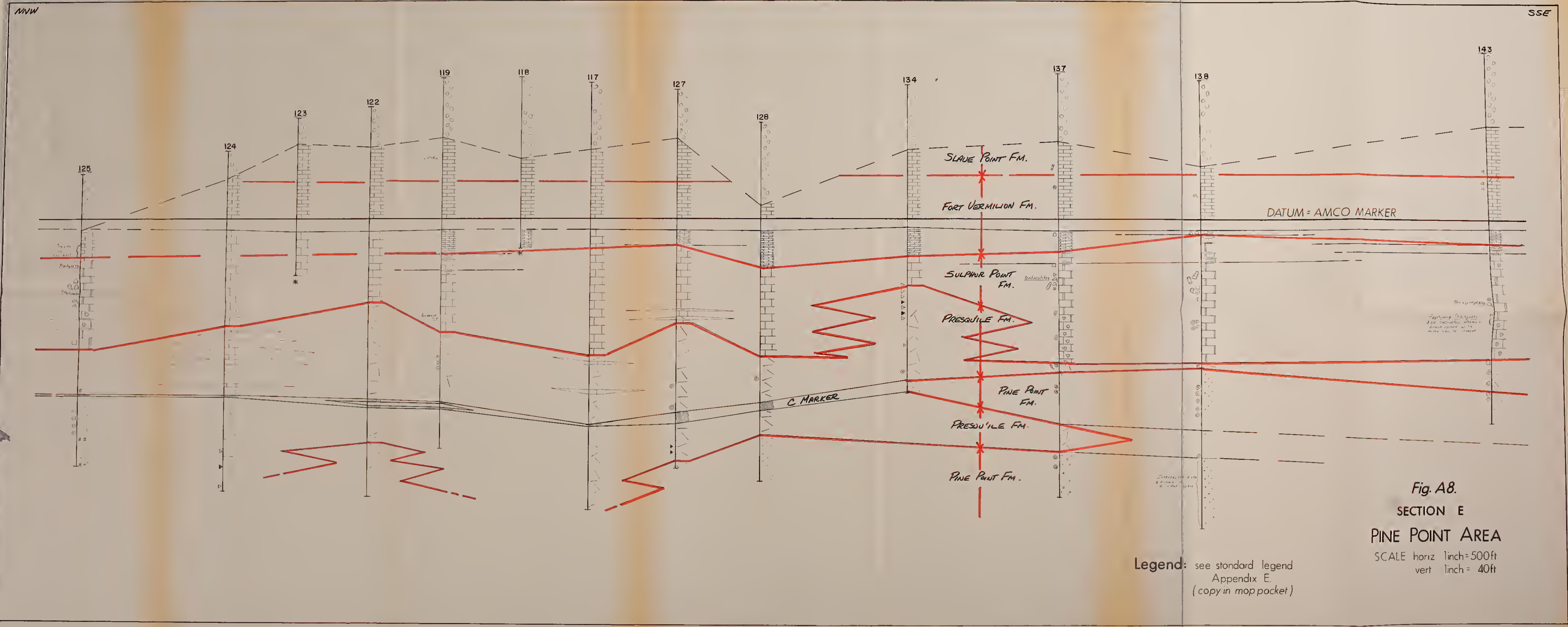


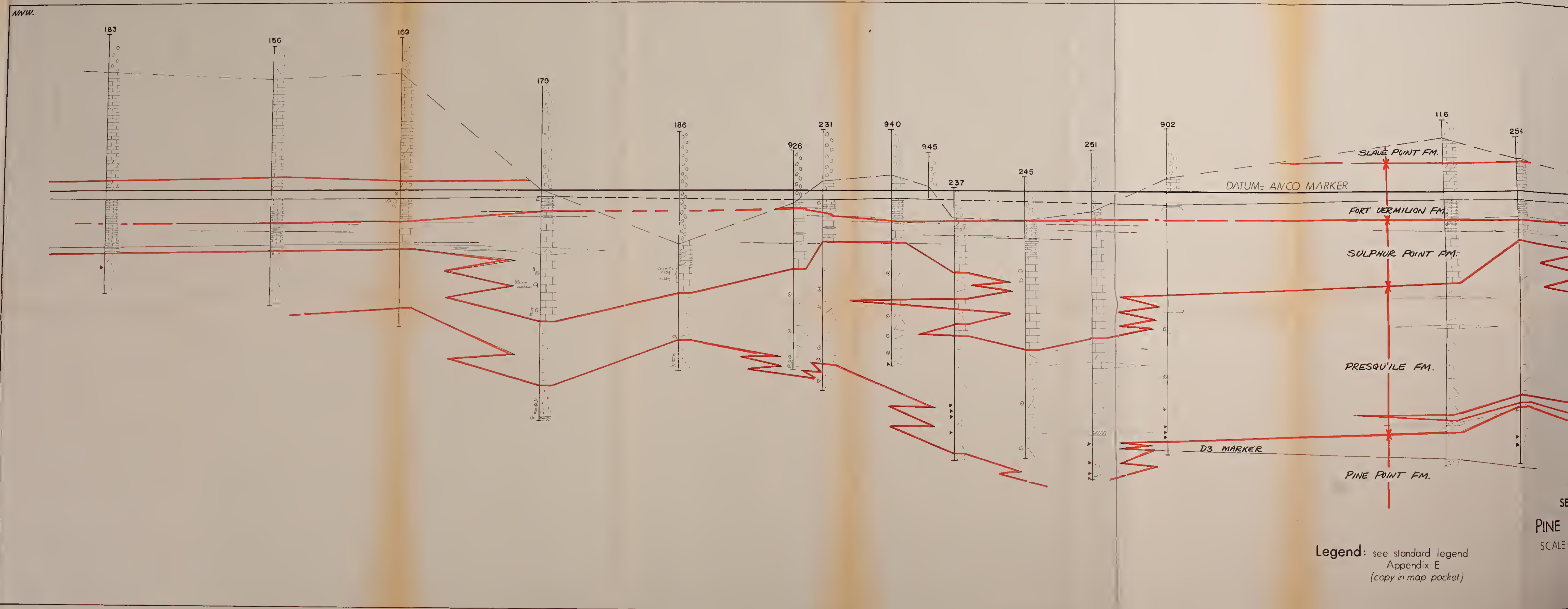
Fig. A7
SECTION Y
PINE POINT AREA
SCALE: horiz 1inch=500ft
vert. 1inch= 40ft.

Legend: see standard legend Appendix E.
(copy in map packet.)



Legend: see standard legend Appendix E. (copy in map pocket)

Fig. A8.
SECTION E
PINE POINT AREA
SCALE horiz 1inch = 500ft
vert 1inch = 40ft



Legend: see standard legend
Appendix E
(copy in map pocket)

SE

PINE

SCALE

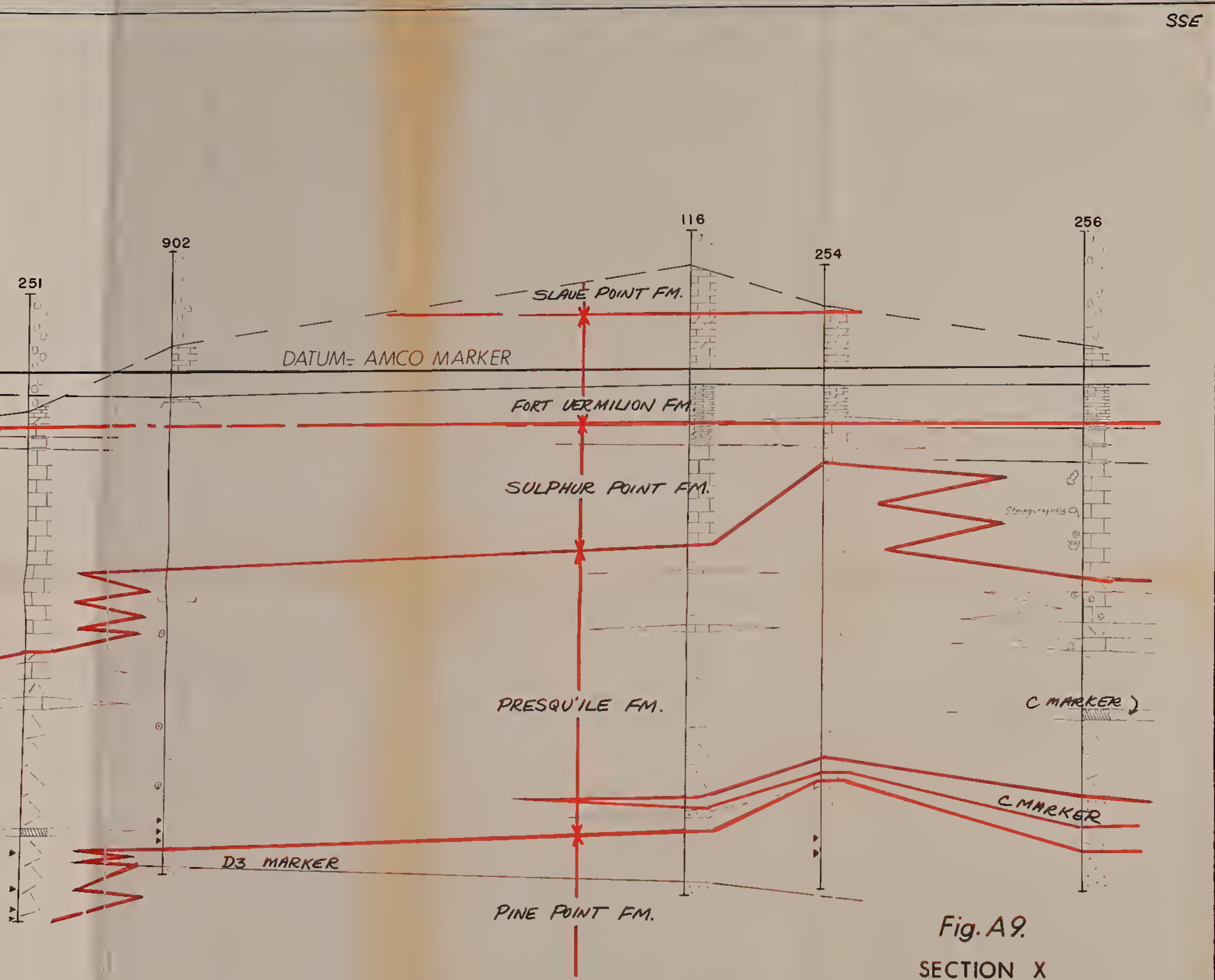


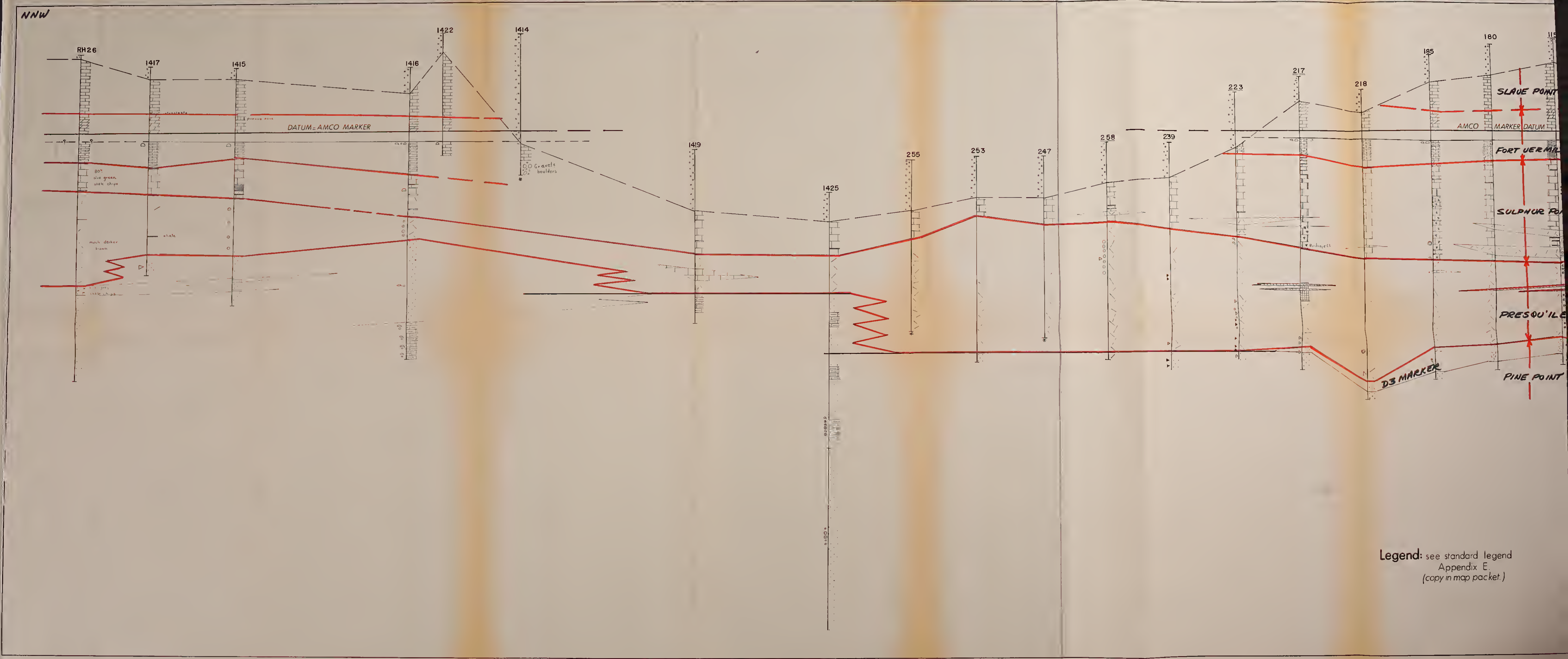
Fig. A9.

SECTION X

PINE POINT AREA

SCALE horiz. 1inch=500ft.
vert 1inch= 40ft

Legend: see standard legend
Appendix E
(copy in map pocket)


NNW
RH26
1417
1415
1416
1422
1414
1419
1425
255
253
247
258
239
223
217
218
185
180
DATUM = AMCO MARKER
Gravels boulders
SLAVE POINT
AMCO MARKER DATUM
FORT VERMIL
SULPHUR PO
PRESQU'ILE
PINE POINT
D3 MARKER
Legend: see standard legend
Appendix E.
(copy in map packet.)

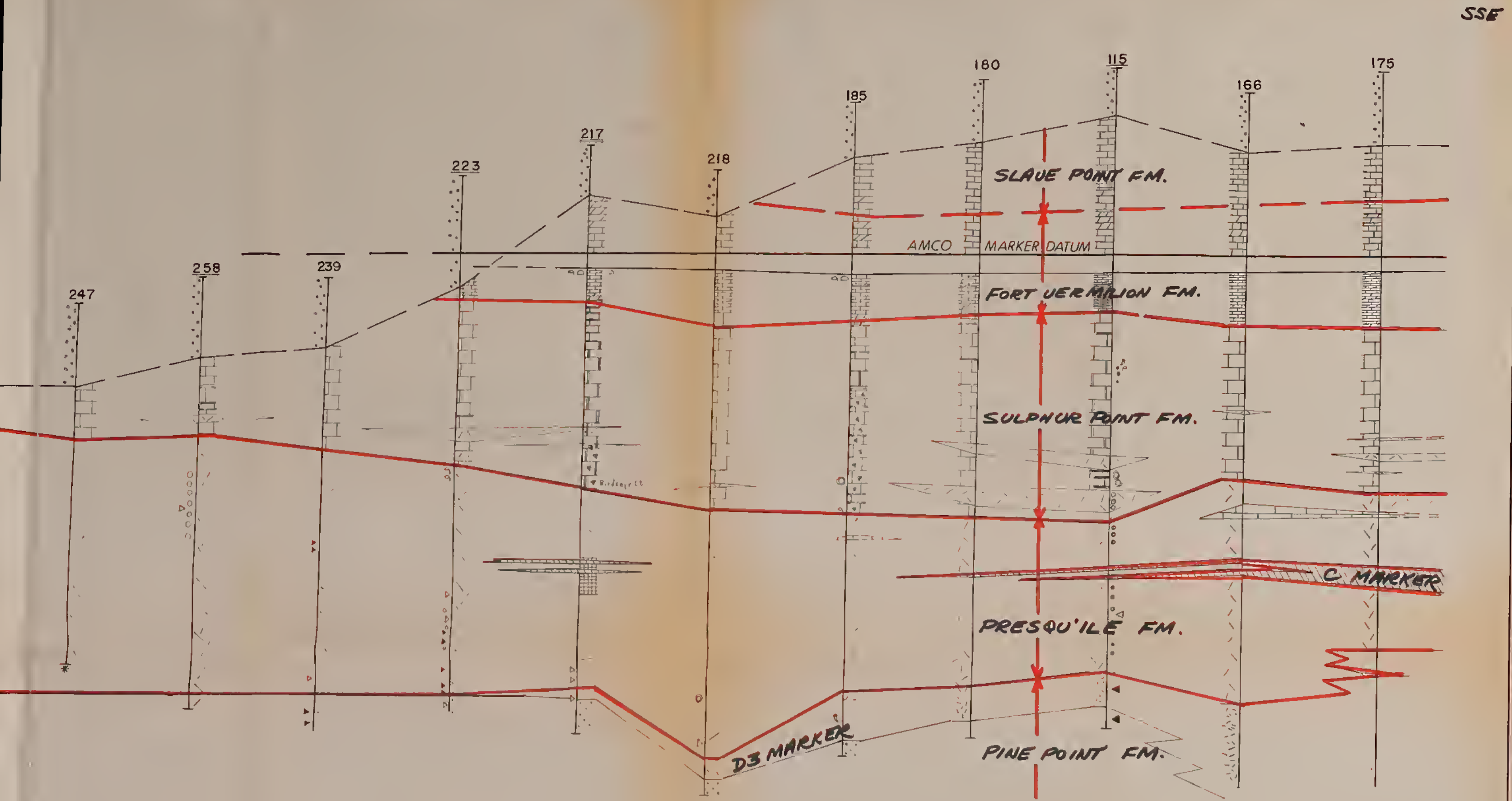


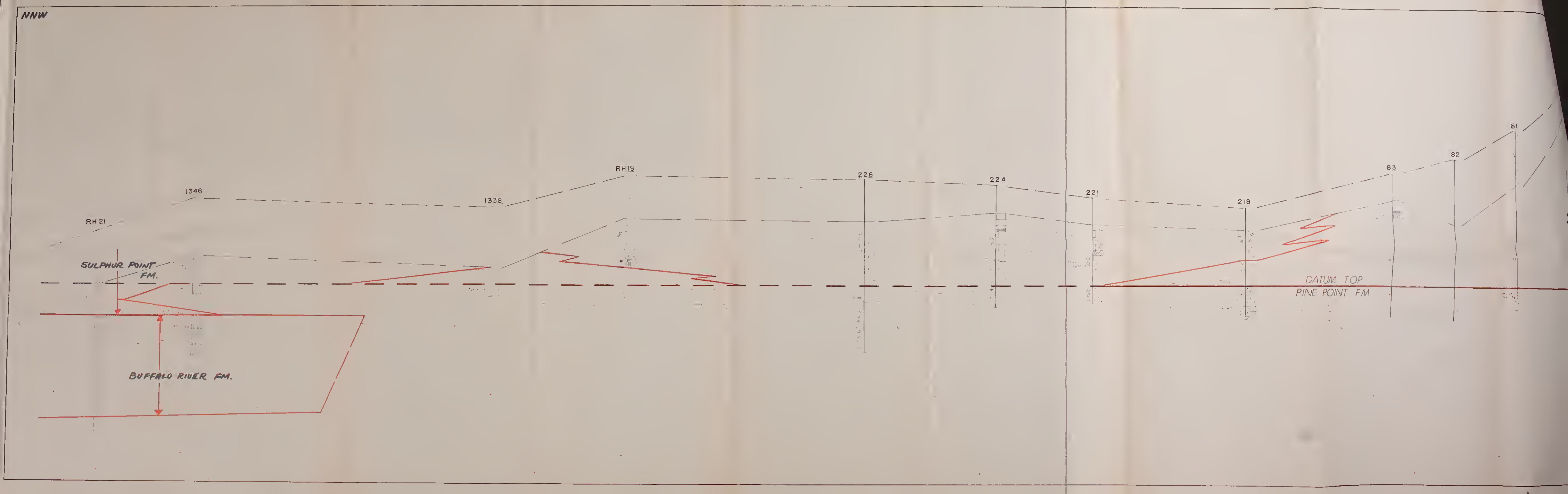
Fig. A10.

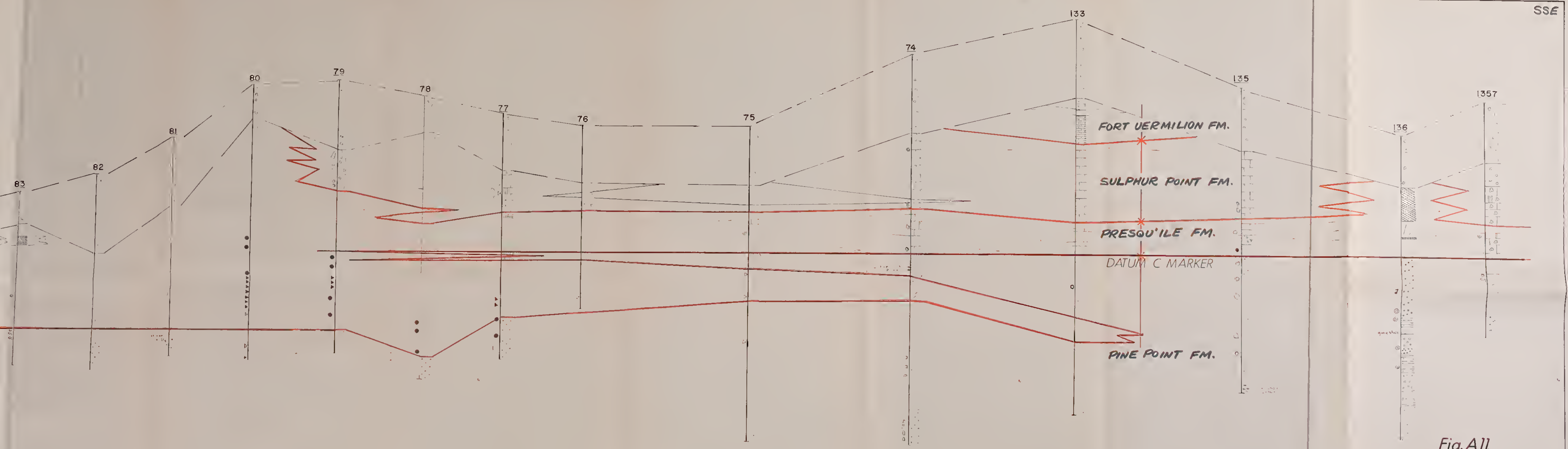
SECTION W.

PINE POINT AREA

SCALE · horiz 1inch=500ft
vert. 1inch= 40ft.

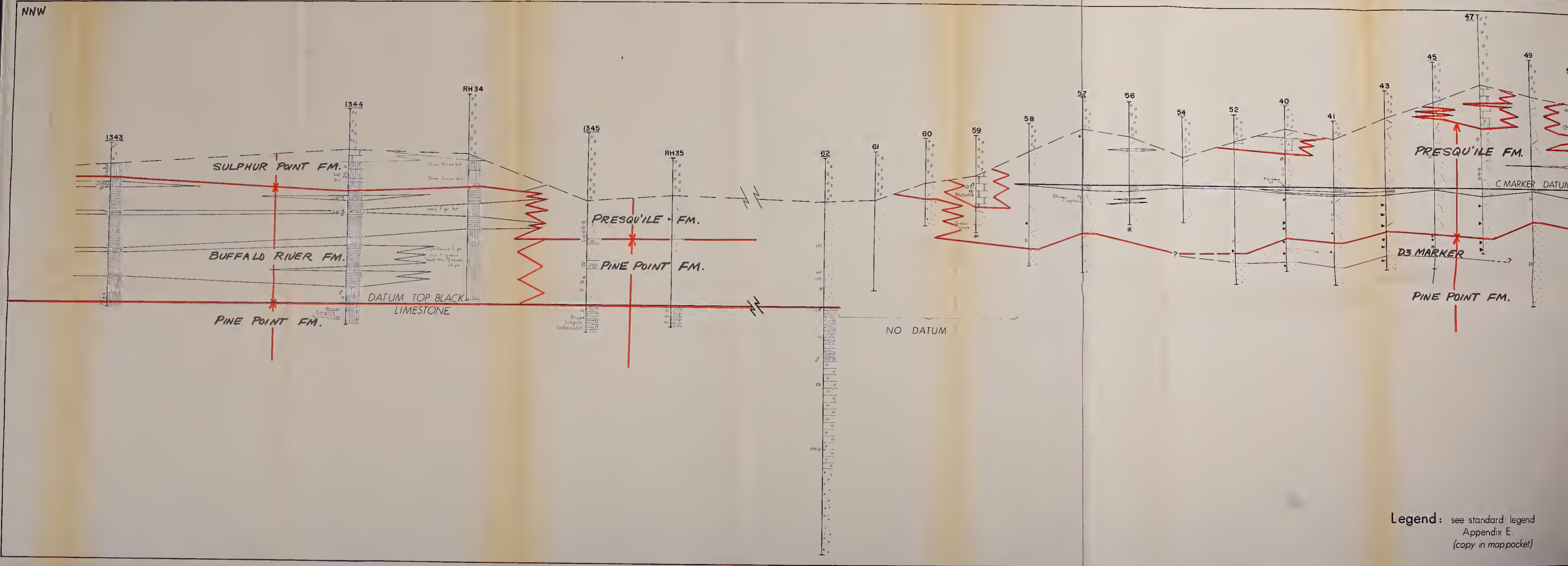
Legend: see standard legend
Appendix E.
(copy in map pocket.)


NNW
RH 21
1346
1338
RH19
226
224
221
218
83
82
81
SULPHUR POINT FM.
BUFFALO RIVER FM.
DATUM TOP
PINE POINT FM

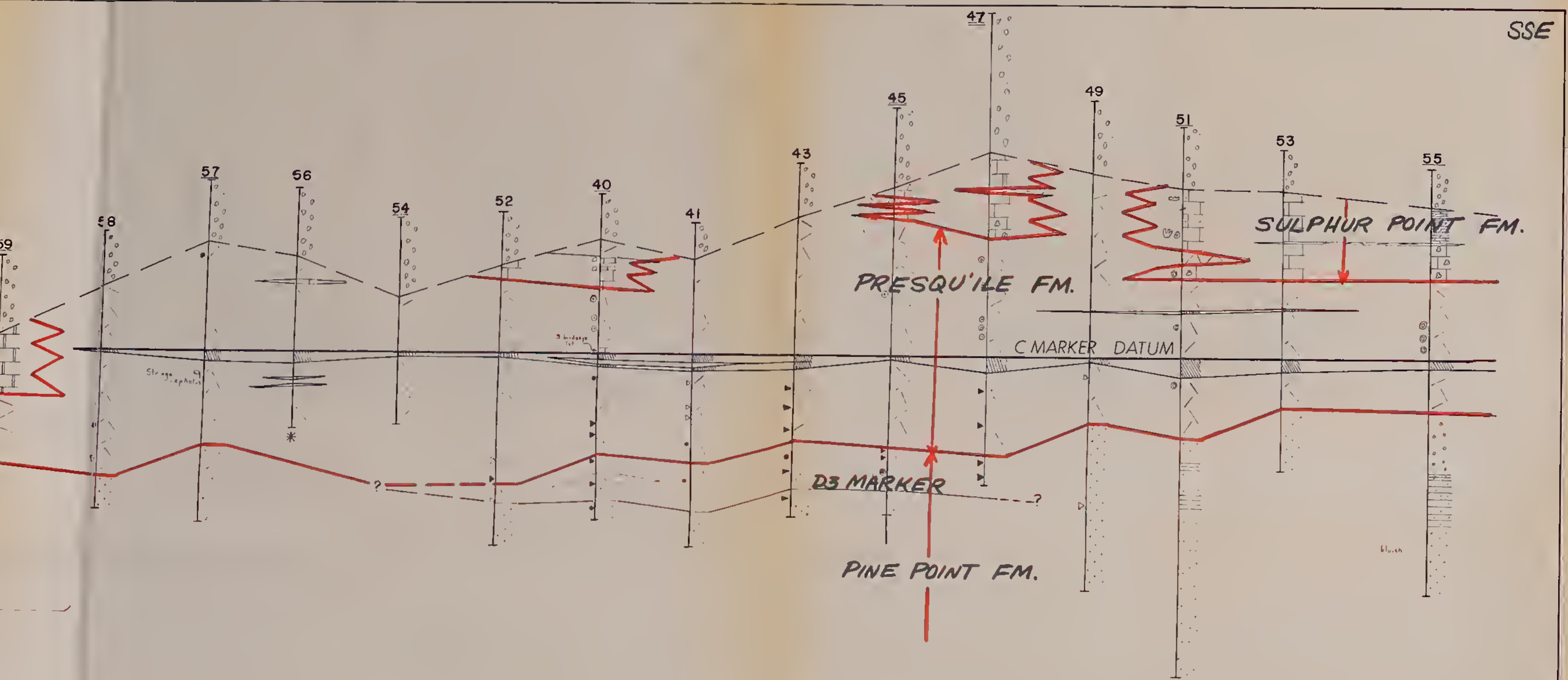


Legend: see standard legend
Appendix E
(copy in map pocket)

Fig. A11.
SECTION D
PINE POINT AREA
SCALE horiz 1inch=500ft
vert. 1inch= 40ft



Legend: see standard legend Appendix E. (copy in map pocket)



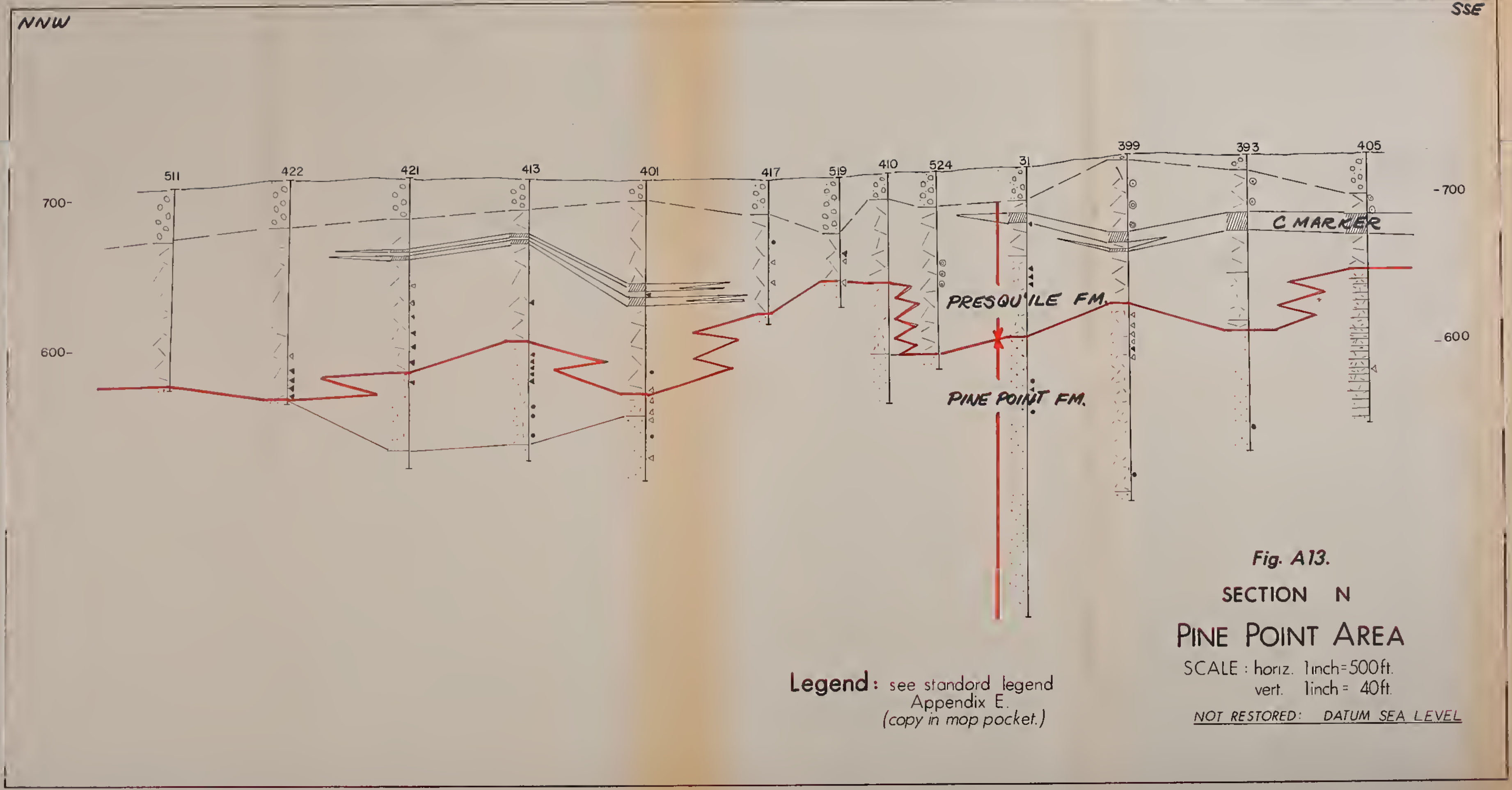
Legend: see standard legend Appendix E. *(copy in map pocket)*

Fig. A12.

SECTION B-C

PINE POINT AREA

SCALE: hariz. 1inch = 500 ft.
vert. 1inch = 40 ft.



Legend: see standard legend Appendix E. (copy in map pocket.)

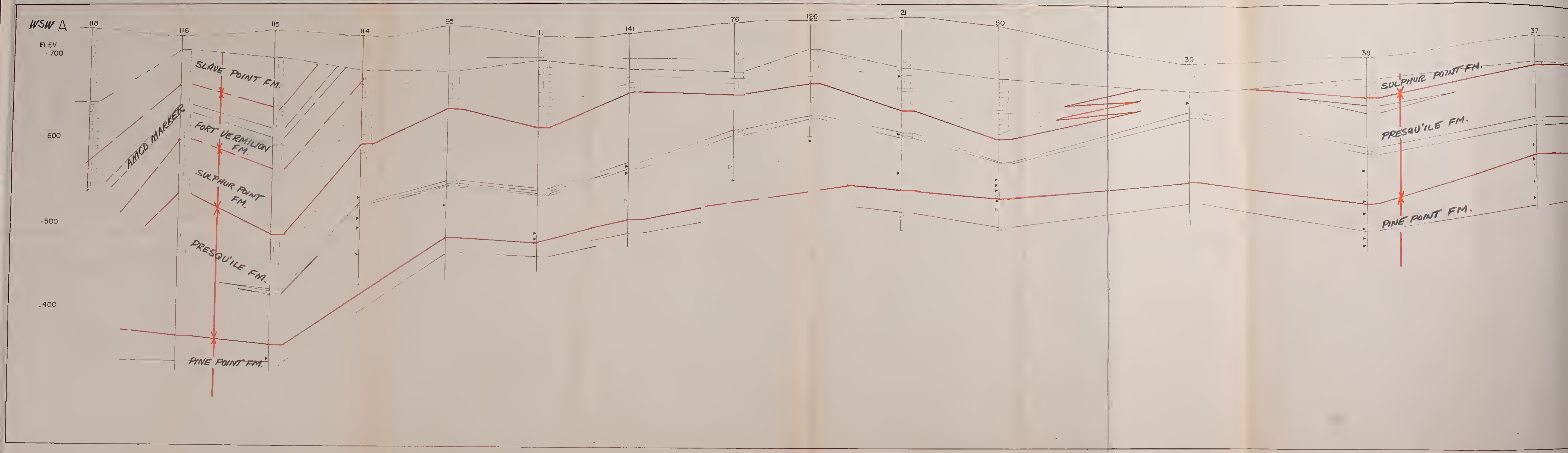
Fig. A13.

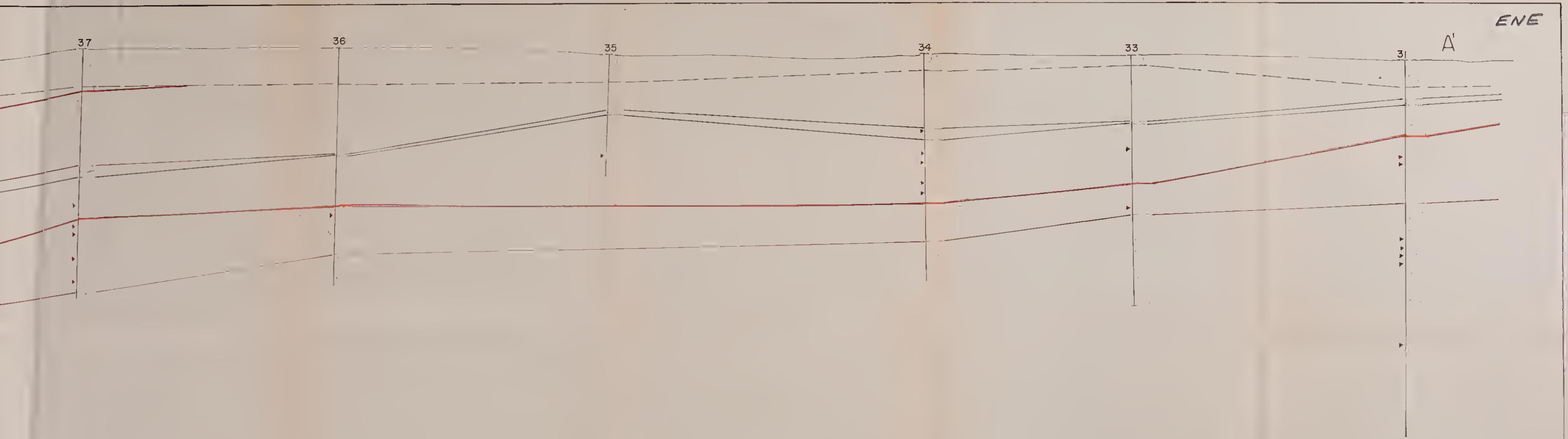
SECTION N

PINE POINT AREA

SCALE : horiz. 1inch=500ft.
vert. 1inch = 40ft.

NOT RESTORED: DATUM SEA LEVEL


WSW A
ELEV
700
600
500
400
118
116
115
114
95
111
141
76
120
121
50
39
38
37
SLAVE POINT FM.
AMCO MARKER
FORT VERMILION FM.
SULPHUR POINT FM.
PRESQU'ILE FM.
PINE POINT FM.
SULPHUR POINT FM.
PRESQU'ILE FM.
PINE POINT FM.



Legend: see standard legend
Appendix E
(copy in map pocket)

Fig. A14.

SECTION A A'

PINE POINT AREA

SCALE : horiz 1 inch = 500 ft
vert 1 inch = 40 ft.

NOT RESTORED: DATUM SEA LEVEL

GREAT SLAVE LAKE
N
SULPHUR POINT
PRESQU'ILE POINT
PINE POINT
DAWSON LANDING
BUFFALO RIVER
PINE POINT TOWN
PYRAMID 202A
ZONE 1
ZONE 2
ZONE 3
ZONE 4
LIMIT OF STUDY AREA
SECTION AA' FIG. A14
CONWEST LINE FIG A2
F LINE FIG A3
FSE LINE FIG A4
Z LINE FIG A5
M LINE FIG A6
Y LINE FIG A7
E LINE FIG A8
K LINE FIG A9
W LINE FIG A10
D LINE FIG A11
B-C LINE FIG A12
N LINE FIG A13
CW 310 1,2
CW 309 1,2
CW 308 1,2
PS 1-6
138000
114000
90000
66000
42000
18000
24000
48000
72000
96000
120000
144000

GREAT SLAVE LAKE
N
SULPHUR POINT
PRESQ'UILE POINT
PINE POINT
DAWSON LANDING
BUFFALO RIVER
ZONE 1
ZONE 2
ZONE 3
PINE POINT TOWN
PYRAMID 202A
LIMIT OF STUDY AREA
SECTION AA' FIG. A14
CONWEST LINE FIG A2
F LINE FIG A3
F5E LINE FIG A4
Z LINE FIG A5
M LINE FIG A6
Y LINE FIG A7
E LINE FIG A8
X LINE FIG A9
W LINE FIG A10
O LINE FIG A11
B-C LINE FIG A12
N LINE FIG A13
138000
114000
90000
66000
42000
18000
24000
48000
72000
96000
120000
144000

GREAT SLAVE LAKE
SULPHUR POINT
PRESQ'UILE POINT
PINE POINT
DAWSON LANDING
BUFFALO RIVER
PINE POINT TOWN
PYRAMID 202A
LIMIT OF STUDY AREA
SECTION AA' FIG. A14
CONWEST LINE FIG A2
F LINE FIG A3
FSE LINE FIG A4
Z LINE FIG A5
M LINE FIG A6
Y LINE FIG A7
E LINE FIG A8
X LINE FIG A9
W LINE FIG A10
O LINE FIG A11
B-C LINE FIG A12
N LINE FIG A13
138000
114000
90000
66000
42000
18000
24000
48000
72000
96000
120000
144000

GREAT SLAVE LAKE
N
SULPHUR POINT
PRESQ'UILE POINT
PINE POINT
DAWSON LANDING
BUFFALO RIVER
PINE POINT TOWN
PYRAMID 202A
LIMIT OF STUDY AREA
SECTION AA' FIG A14
CONWEST LINE FIG A2
F LINE FIG A3
F5E LINE FIG A4
Z LINE FIG A5
M LINE FIG A6
Y LINE FIG A7
E LINE FIG A8
X LINE FIG A9
LINE FIG A10
D LINE FIG A11
B-C LINE FIG A12
LINE FIG A13
138000
114000
90000
66000
42000
18000
24000
48000
72000
96000
120000
144000

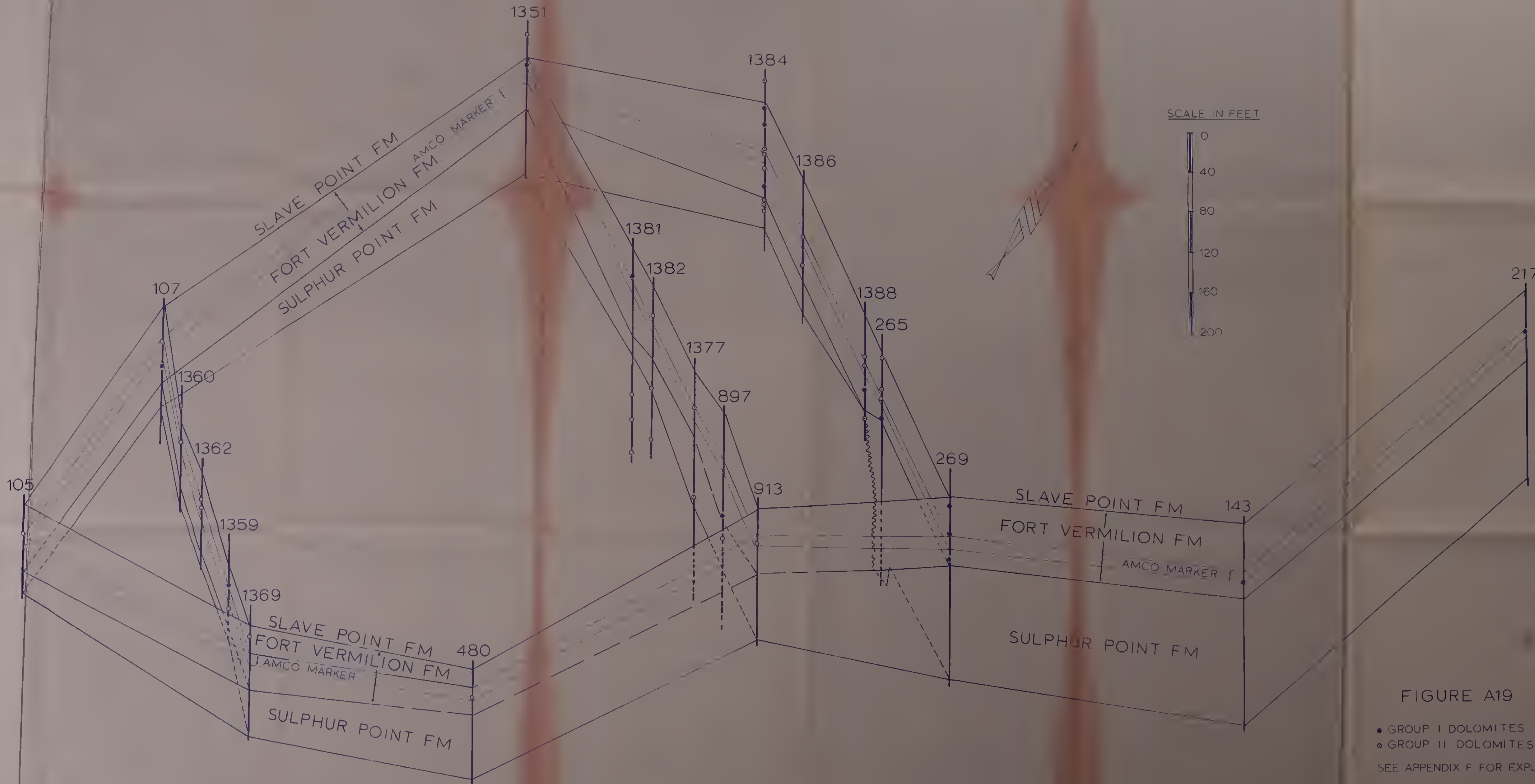


FIGURE A19

• GROUP I DOLOMITES
○ GROUP II DOLOMITES

SEE APPENDIX F FOR EXPLANATION